Phase II Report

COMPUTER PROGRAM

A MICROCOMPUTER FINITE ELEMENT SOFTWARE FOR THE DESIGN OF STEEL SUPPORT SYSTEMS WITH SPECIAL REFERENCE TO THE DONKIN MORIEN PROJECT

Submitted by:

Dr. F.P. Hassani

and

Dr. H.S. Mitri

Department of Mining and Metallurgical Engineering

McGill University, Montreal, Quebec, H3A 2A7

Submitted to:

Department of Energy, Mines and Resources

CANMET - CRL Division

Cape Breton Coal Research Laboratory

210 George St.

Sydney, Nova Scotia

B1P 1J3

DSS Contract No: 63 SS. 23440-7-9054-01-39

Date: June 1989

145 pp

MICROMEDIA

91-00302/

ABSTRACT

A finite element program called S4 (Steel Set Support Systems) has been developed. The mathematical formulations on which this program is based are described in a previous report written by the authors under the same Research Agreement (Phase I Report of this project, March 1988). The main objective of this Phase II Report is to provide the necessary information for the use of the program in the design and analysis of tunnel steel supports from open steel I or H sections under various loading conditions.

The work is presented in two parts, Part 1 which is intended to serve as a user's manual and Part 2 which reports the results of a comprehensive variation of parameter study. The information in the latter Part may be used directly for design purposes when the site conditions (tunnel geometry, loading, section size, etc.) match with those cited in the parametic study.

The program is written in FORTRAN and runs on personal computers like IBM AT, PS/2 and compatibles. It is comprised of a main program and thirty-two subroutines which amount to some 1900 statements of code. A computer listing of the source code is provided and the functions of all subroutines are described.

TABLE OF CONTENTS

ABSTRACT	page (ii)
TABLE OF CONTENTS	page (iii)
LIST OF FIGURES AND TABLES	page (iv)
PART 1 : USER'S TECHNICAL REFERENCE	
1.1 PROGRAM S4	page 1
1.2 LIST OF SUBROUTINES	page 9
1.3 USER'S MANUAL	page 11
1.4 INTERPRETATION OF PROGRAM'S OUTPUT	page 19
1.5 NUMERICAL EXAMPLES	page 21
PART 2 : VARIATION-OF-PARAMETER STUDY	
2.1 LOAD DISTRIBUTION	page 60
2.2 SECTION SIZE	page 61
2.3 DIAMETER	page 61
2.4 LEG-TO-OVERALL HEIGHT RATIO	page 61
2.5 SPLAY LEG ANGLE	page 61
2.6 DISCUSSION	page 62
REFERENCES	page 62
APPENDIX : PROGRAM LISTING	page 99

LIST OF FIGURES AND TABLES

Figure 1.1 : Structure of Program S4

Figure 1.2 : Support types

Figure 1.3 : Loading conditions

Figure 1.4 : Some examples of translation/rotation codes

Figure 1.5 : Geometric parameters of cross section

Figure 1.6 : Element types

Figure 1.7 : Distribution of numerical integration points within an element

Figure 1.8 : Datafile of example 1

Figure 1.9 : Output file of example 1

Figure 1.10 : Datafile of example 2

Figure 1.11 : Output file of example 2

Figure 1.12 : Yielding of elements proir to support failure (Example 2)

Figure 1.13 : Datafile of example 3

Figure 1.14 : Output file of example 3

Figure 1.15 : Yielding of elements prior to failure (Example 3)

Figure 1.16 : Datafile of example 4

Figure 1.17 : Output file of example 4

Figure 1.18 : Yielding of elements prior to failure (Example 4)

Figure 2.1 : Effect of loading condition on load having capacity of steel support

Figure 2.2 : Effect of section size

Figure 2.3 : Effect of diameter

Figure 2.4 : Effect of leg-to-overall height ratio

Figure 2.5 : Effect of splay leg angle

Table 2.1 : Geometric Properties of H-Sections used as Steel Supports

Table 2.2 : Effect of Load Distribution on the Behaviour of Different Supports

Table 2.3 : Model Data and Results of Shape Effect Analysis

Table 2.4 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

Table 2.5 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

Table 2.6 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

Table 2.7 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

Table 2.8 : Effect of Sinusoidal Load Distribution on the Behaviour of Semi-circular Arch

Table 2.9 : Effect of Sinusoidal Load Distribution on the Behaviour of Splay Leg Arch (A-Type)

Table 2.10 : Effect of Sinusoidal Load Distribution on the Behaviour of Splay Leg (A-Type)

Table 2.11 : Effect of SInusoidal Load Distribution on the Behaviour of Splay Leg Arch (A-Type)

Table 2.12 : Effect of Sinusoidal Load Distribution on the Behaviour of Circular Arch

PART 1

USER'S TECHNICAL REFERENCE

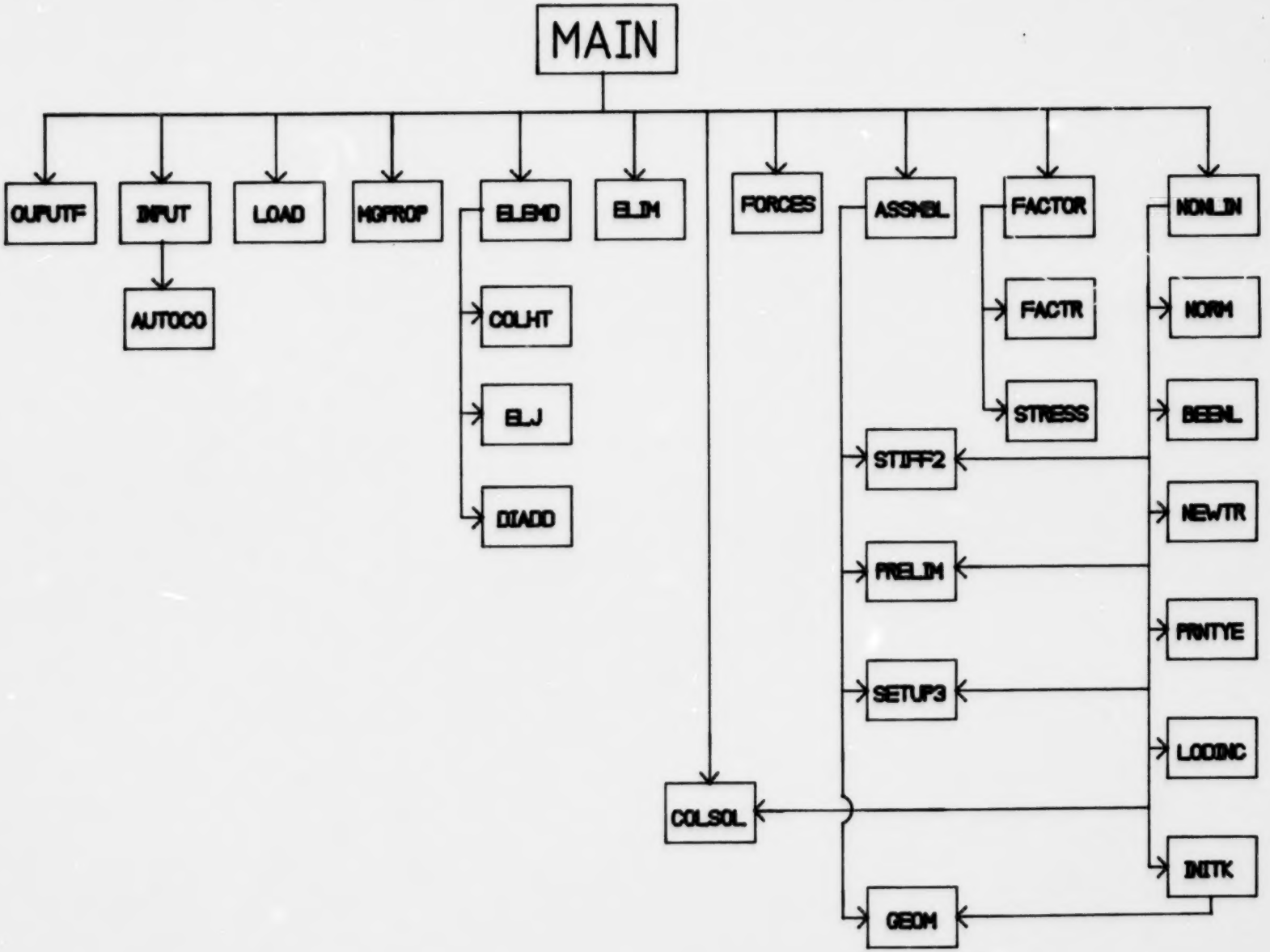
1.1 PROGRAM S4

A finite element program called s4 (Steel Set Support Systems) has been written for use on IBM personal computers like XT, AT, PS/2 and Compatibles. The program is coded in standard FORTRAN 77 and compiled by Microsoft Fortran Compiler. It comprises some 1900 statements and consists of a main and 32 subroutines, see program's structure on Fig.1. The required input data for the program is simplified such that only the information related to the physical problem is supplied. Nodal coordinates and element connectivity arrays, normally required by any conventional finite element program, are automatically generated. This has the advantages of saving time and avoiding human errors. The program's input data include: (1) Problem identification, (2) Support type, (3) Support geometry, (4) Load type and (5) Material properties.

Four support types have been incorporated in S4. As shown in Fig.2, these are the circular (C-type), semi-circular (SC-type), semicircular with vertical legs (D-type) and semicircular with splay legs (A-type). These types are believed to cover a wide range of applications in Canadian mining operations. Four loading conditions are accounted for in the program, see Fig.3. The user may select: (1) Concentrared gravity load at the crown point, (2) Uniform gravity load over the full length or a portion of the crown, (3) Nonuniform gravity load (peaking at the crown point and decreasing gradually towards the bases) which may be applied over the full length or a portion of the crown and (4) Radial pressure. Furthermore, the user may simulate any arbitrary loading condition. The required material properties are Young's modulus of elasticity and uniaxial yield stress. The program runs in batch mode, i.e. a datafile is prepared, using any editor, prior to running the program. To facilitate data preparation, all input data can be written in free format.

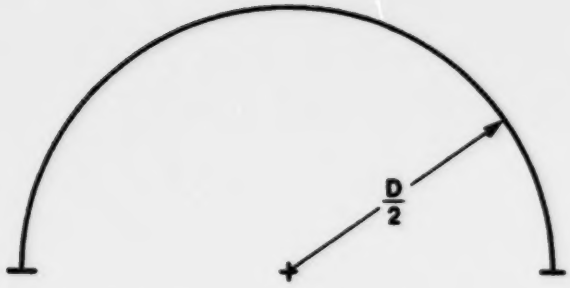
The output of program S4 is comprehensive. It provides complete information on the load-deformation history of the support up to the point of collapse. At any given load

level, the corresponding dispalcements and the extent of yield zones within the support section can be determined. The latter is done by checking the stress level at all integration point within each element (21 points). The load is increased automatically in increments and the results (displacements and stresses) are printed at the end of each load increment. The output is terminated when collapse is encountered and a summary of results is printed. The output of S4 may be stored on a file, routed to the printer, or viewed on the personal computer screen.

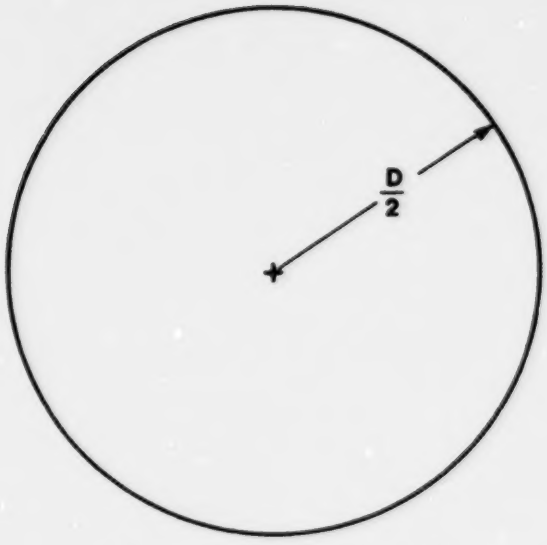


Subroutines PSET, PRESET, COPY, TRANS and ERROR are not shown in the above. These perform standard jobs and they are used at various locations in the program.

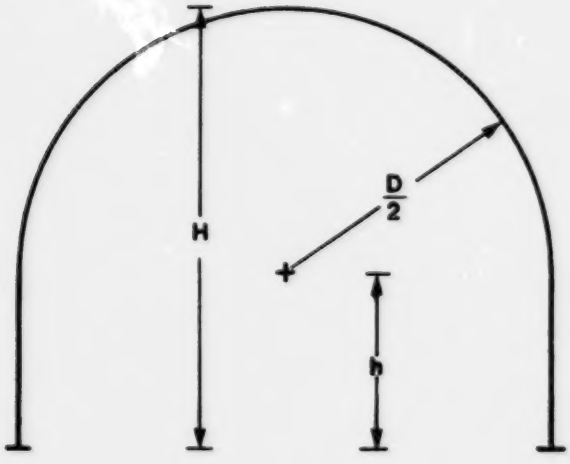
Fig. 1.1 : Structure of Program S4



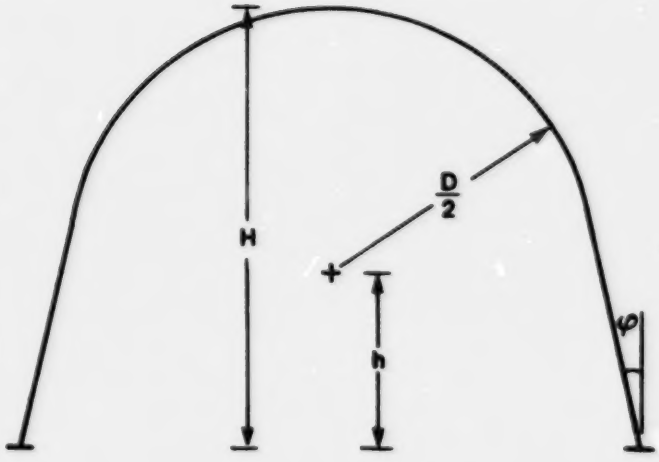
(a) Semicircular (SC-type)



(b) Circular (C-type)



(c) Arch (D-type)



(d) Arch with splay legs (A-type)

Fig. 1.2 : Support types

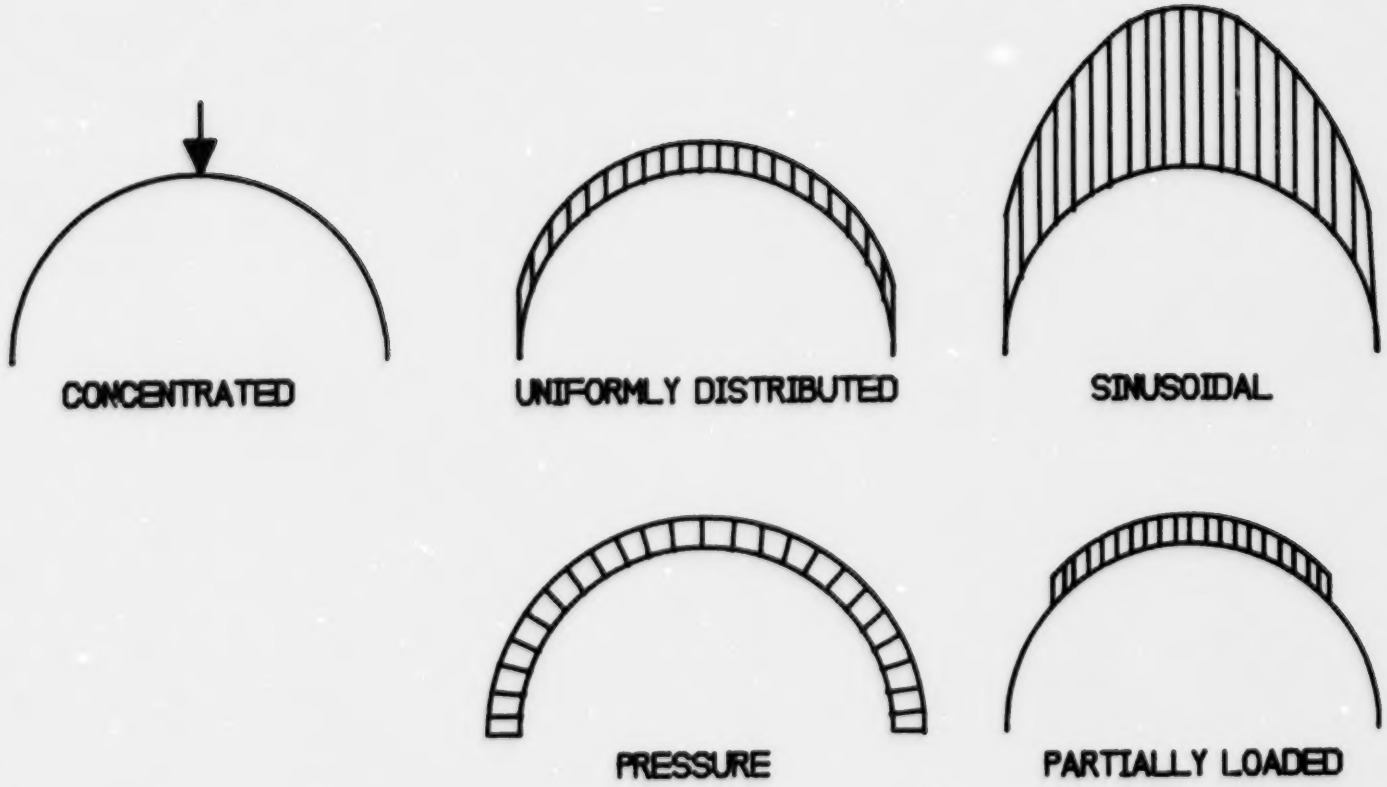


Fig. 1.3(a) : Loading conditions

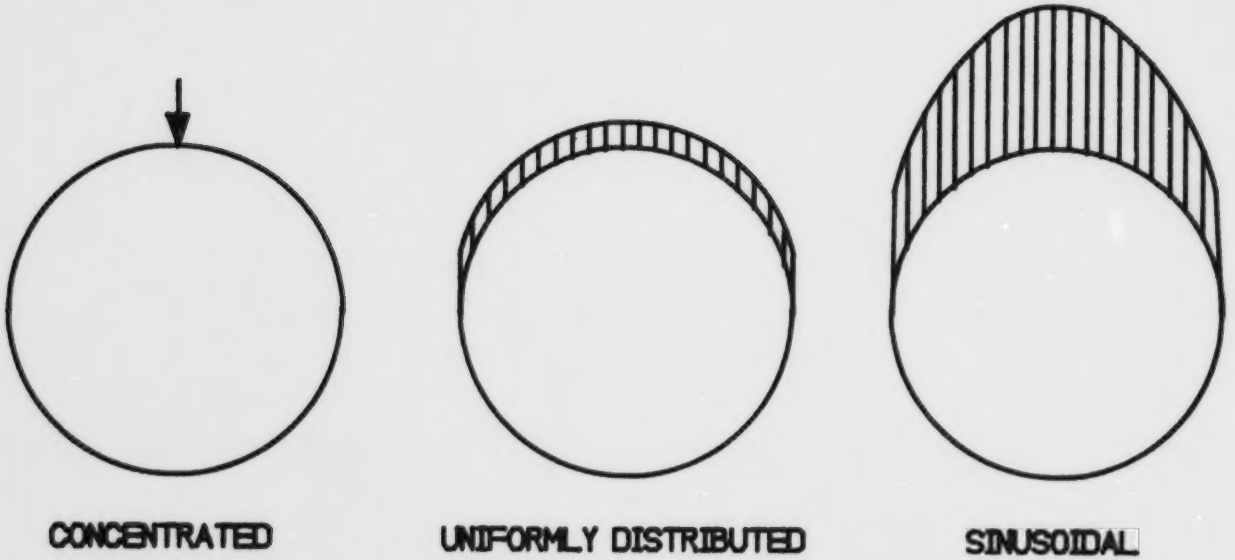


Fig. 1.3(b) : Loading conditions

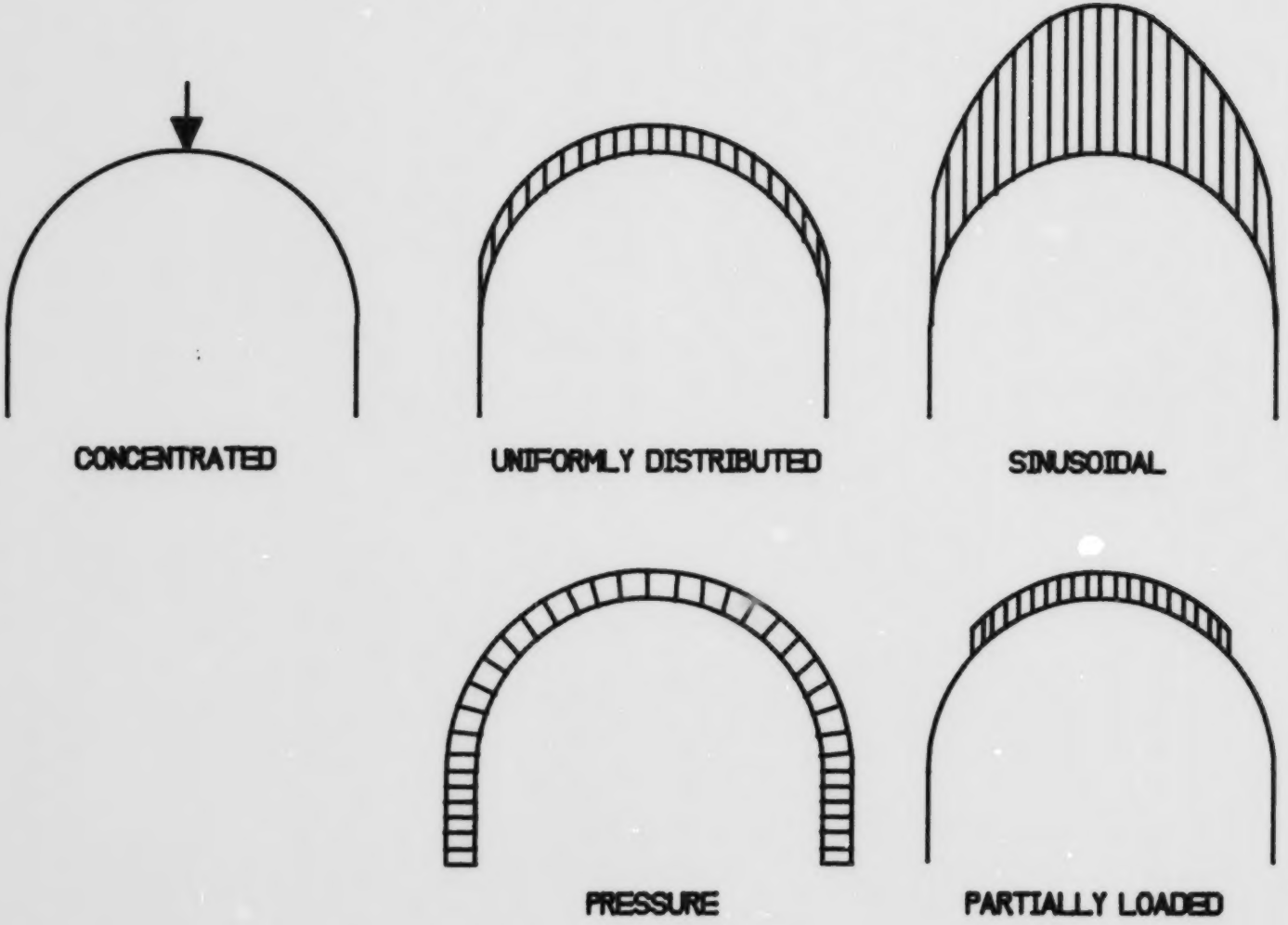


Fig. 1.3(c) : Loading conditions

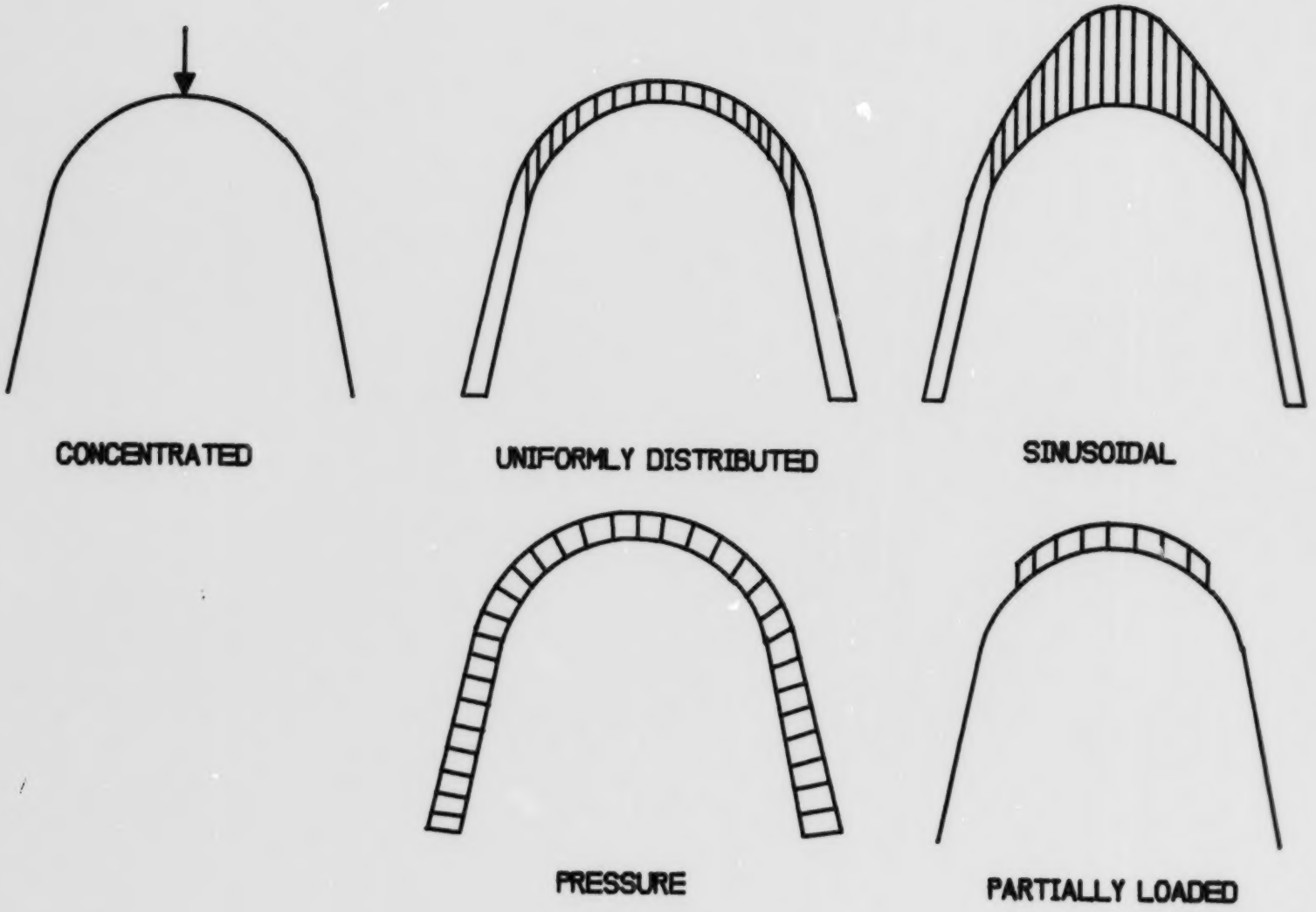


Fig. 1.3(d) : Loading conditions

1.2 LIST OF SUBROUTINES AND THEIR FUNCTIONS

No.	*SUBROUTINE*	*FUNCTIONS*
1.	ASSMBL	Compute individual element stiffness matrices and assemble them in a skylined global matrix.
2.	AUTOCO	Generate the nodal coordinates and boundary conditions of different support types.
3.	BEENL	Calculate the nonlinear strain matrix.
4.	COLHT(1)	Calculate the column heights of a matrix.
5.	COLSOL(1)	Solve finite element static equilibrium equations in core, using a compacted storage and column reduction scheme.
6.	COPY	Copy one array onto another.
7.	DIAADD(1)	Calculate the diagonal element addresses of skylined matrix.
8.	ELEMD	Compute the relevant element data and store on scratch files
9.	ELIM	Compute and print reference loads and displacements of first load increment.
10.	ELJ(2)	Build element connectivity array.
11.	ERROR	Report error message for insufficient dynamic storage.
12.	FACTOR	Control the search for maximum stress and perform the scaling of stresses and strains.
13.	FACTR	Compute the maximum stress within the element.
14.	FORCES	Calculate the end forces of an element
15.	GEOM	Compute the geometric stiffness matrix.
16.	INITK	Compute initial stiffness matrix.
17.	INPUT	Read and print node and element data.

Cont'd LIST OF SUBROUTINES AND THEIR FUNCTIONS

No.	*SUBROUTINE*	*FUNCTION*
18.	LOADS	Read nodal forces and generate load vector(s).
19.	LODINC	Automatic control of load increment size.
20.	MGPROP	Read and print material properties.
21.	NEWTR	Update the element transformation matrix
22.	NONLIN	Carry out nonlinear analysis
23.	NORMS	Compute the norm of an array
24.	OUPUTF	Create output file names with extensions.
25.	PRELIM	Compute point co-ordinates and weight factors.
26.	PRESET(2)	Zero a two dimensional array.
27.	PRNTYE	Print stresses and strains of yielded elements.
28.	PSET(2)	Zero a one dimensional array.
29.	SETUP3(2)	Assemble a skylined matrix.
30.	TRANS(2)	Transform the element stiffness matrix from local to global coordinates.
31.	STIFF2	Compute stiffness matrix of beam elements.
32.	STRESS	Calculate the element stress and strain increments.

1.3 USER'S MANUAL

The following is a description of the input data to program S4. With the exception of the Heading Card which should not exceed one line (80 characters) of text information, all data cards are format free.

I. Heading Card (20A4)

Variable	*Entry*
TITLE(20)	Enter the master heading information for use in labelling the output.

II. Control Card

Variable	*Entry*
NPROB	Problem number
MODE	=0, data check only =3, nonlinear analysis solution
NOD	Total number of nodes
NEL	Total number of elements
NSTP	Type of support =0, general structure =1, semicircle =2, arch =3, splay arch =4, circle under pressure =5, circle not under pressure
NLTP	Type of load =0, General Load =1, Uniform Load =2, Sinusoidal Load =3, Pressure Load
NSGE	Number of sections used in structure

III.a SUPPORT GEOMETRY
IF NSTP = 0, skip this card

Variable	*Entry*
D	Support diameter
H	Support height
SLA	Splay leg angle measured from horizontal

III.b. Nodal Point Cards (NOD Cards)
IF NSTP > 0, skip this card.

Variable	*Entry*
M	Node number
X	X - co-ordinate
Y	Y - co-ordinate
IX(1)	U - translation code in x-direction*
IX(2)	V - translation code in y-direction*
IX(3)	O - rotation code*

* translation/rotation code:(see examples on Fig.1.4)
=1, free degree of freedom
=0, fixed (locked) degree of freedom

IV. Geometry of Cross Sections (NSGE cards),

Variable	*Entry*
ISEC	Section number
BFL(ISEC)	Flange width, see Fig.1.5
TFL(ISEC)	Flange thickness
DWB(ISEC)	Web depth
TWB(ISEC)	Web thickness

V. Element Data Cards (NEL cards)

IF NSTP > 0, skip

Variable	*Entry*
M	Element number
ICO(1,M)	First node number of element
ICO(2,M)	Second node number of element
IT(M)	Index for element type =1, if element is pin-pin, =2 for fix-fix, =3 for pin-fix, =4 for fix-pin, see Fig.1.6
IS(M)	Index to speed calculation when possible, =1 if element is identical to (M-1 st) element in length, size and orientation, =0 otherwise
ISEC(M)	cross section number of element.

VI. Concentrated Load Control Data Card

Variable	*Entry*
NLW	Number of nodes under incremental concentrated load

VII. Distributed Load Control Data Card

Variable	*Entry*
NLMV	Number of elements under incremental distributed load (when NSTP = 0); OR Loaded length in percentage of projected crow length (when NSTP > 0)

VIII. Data Cards For Concentrated Loads

IF NLW = 0, skip this group

IF NLTP > 0, skip this group

Variable	*Entry*
NOC(I)	Node number subject to concentrated load
FX(I)	Reference load in x-direction
FY(I)	Reference load in y-direction
BM(I)	Reference bending moment

IX. Data Cards For Distributed Loads

IF NLMV=0, or NLTP>0 skip this group

Variable	*Entry*
M	Element number
WXG	Uniformly distributed load in x-direction
WYG	Unifromly distributed load in y-direction

X. Material Properties

Variable	*Entry*
E	Young's modulus
ET	Tangent modulus
SIGY	Yield stress
SIGU	Ultimate stress

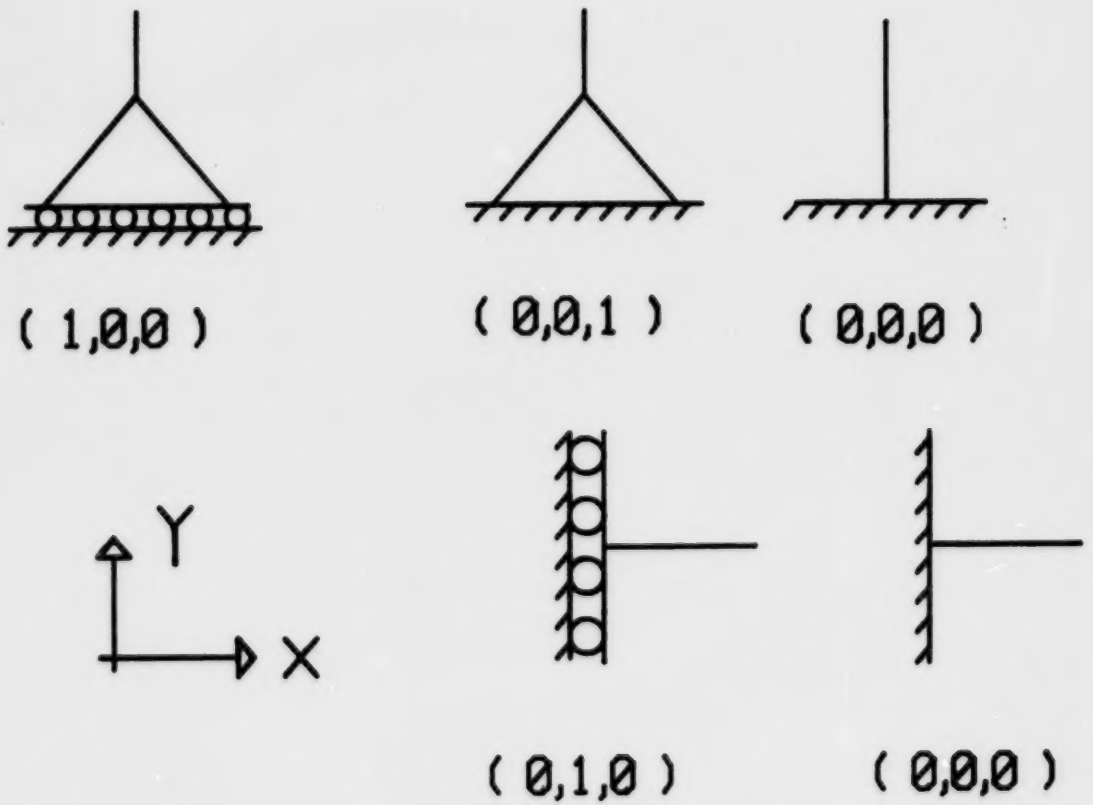


Fig. 1.4 : Some examples of translation/rotation codes

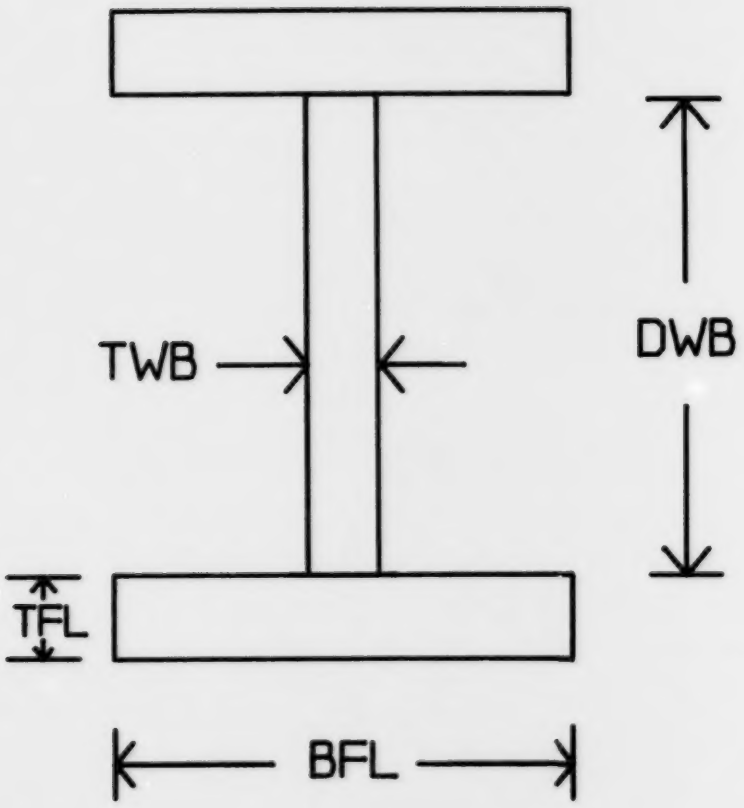


Fig. 1.5 : Geometric parameters of cross section

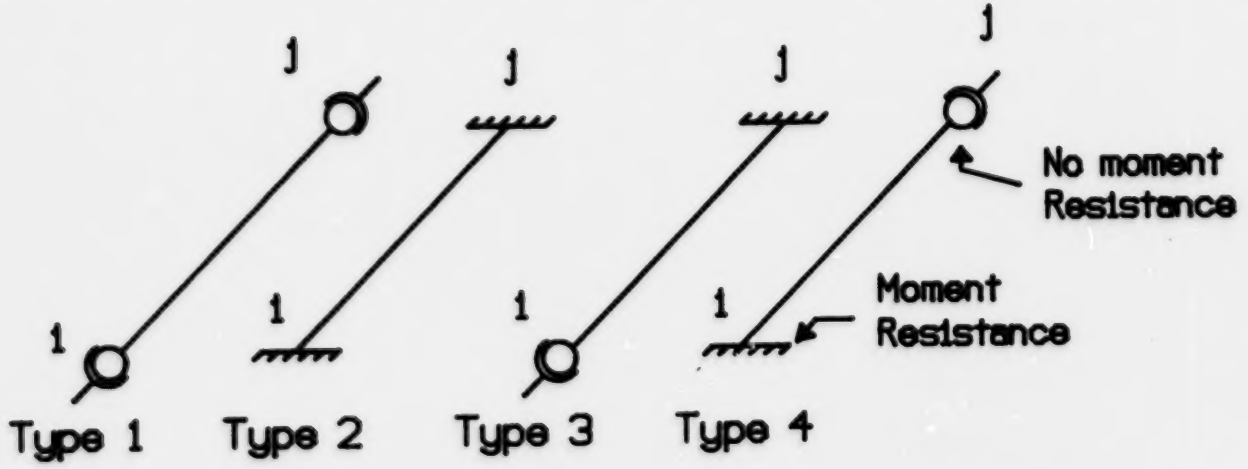


Fig. 1.6 : Element types

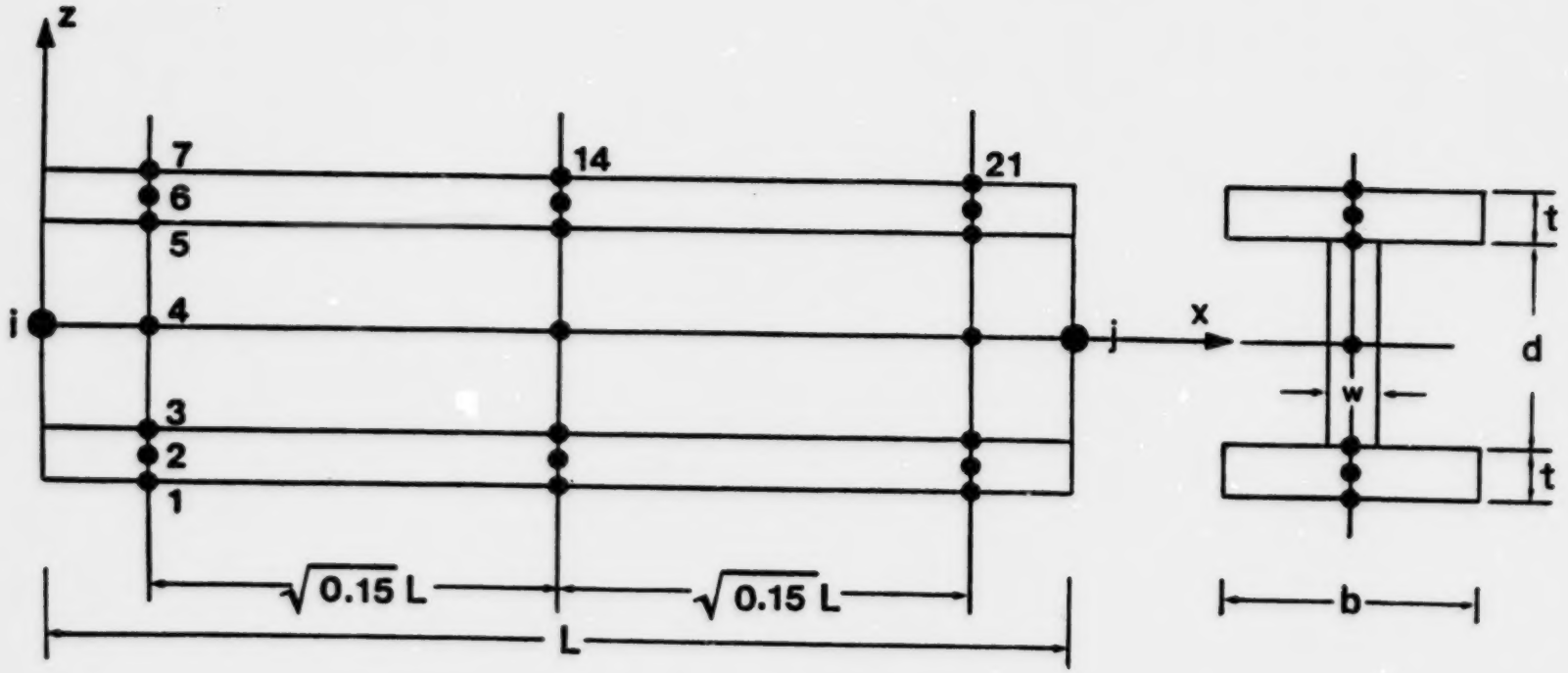


Fig. 1.7 : Distribution of numerical integration points within an element

1.4 INTERPRETATION OF PROGRAM'S OUTPUT

Program S4 produces two output files bearing the same name as the datafile but with extensions DOC and PDE. The DOC file contains comprehensive information about the data and results of a computer run, whereas the PDE file contains only the load versus crown deflection results which can be used specifically to obtain the load deformation characteristic curve of the steel set. The printout of the DOC file shows the following information:

a. **General information:** problem title, support type, loading condition, number of steel sections used and support geometry (diameter, height, angle of splay leg).

b. **Nodal point data:** these are generated by the program for the purpose of finite element discretization of the steel set. Each node appears with its x-y coordinates and degrees-of-freedom.

c. **Element data:** these are also generated by the program. The dimensions of cross section as well as the connecting nodes for each element are printed.

d. **Initial load data:** this part represents the loading condition as initially set by the program e.g., a unit load for concentrated load, unit load/unit length in case of distributed load, etc.

e. **Material properties:** This is simply a printout of the user-supplied information on the steel material of the support.

f. **Solution for load increment no.1:** The most important part of the output here is the line defining what is called "Reference Load", which is equal to the Initial Load multiplied

by a factor computed by the program. The next part of this output is the "Nodal Displacements" which gives the displacements in x and y directions of each node as a result of the application of Load Increment No.1.

g. **Subsequent load increments:** The output of these sections are much similar to that of Load Increment No.1, except that it starts by updating the load level to a multiple of the Reference Load as the loading increases. This is followed by a printout of Nodal Displacements. When these is no yielding yet detected in the elements, the results for a particular load increment finish at this point. Otherwise, information about the elements in which yielding was found are printed. Such information gives the integration point within the element (1 to 21), its location the normal stress (> yield stress in case of yielding) and strain, see Fig 1.7 for distribution of integration points within one element.

h. **Summary of results:** When failure is imminent, the solution does not coverage and a statement is printed to that effect. A summary of the results showing the maximum load level sustained is then printed.

1.5 NUMERICAL EXAMPLES

This section is aimed to provide a simple guide to the use of Program S4 through some illustrative numerical examples. Four cases are presented which are for semicircular, circular, D-type and A-type steel sets. In each example, the input data file as well as the relevant parts of the output file are shown and the calculation of the load bearing capacity is presented.

EXAMPLE 1 : Semi Circular Support

The first example is of a 4-m diameter, semicircular support subjected to uniformly distributed data load. The cross sectional properties are as follows:

Flange width	= 102 mm
Flange thickness	= 10.3 mm
Net web depth	= 81.4 mm
Web thickness	= 9.5 mm
Young's modulus of elasticity	= 200 GPa
Yield stress	= 268 MPa
Tangent modulus	= 0 (perfectly plastic)

The datafile is shown in Fig. 1.8. The objective is to find the maximum load that can be sustained by the steel set. The output file shown in Fig. 1.9 shows that the maximum load level is given by 5.60 x Reference Load where:

Reference Load = 0.0114 x Initial Load

and

Initial Load	= 1.00 KN
Max load level	= 5.6 x 0.0114 x 1.00 = 0.06384 KN/mm
	= Max load intensity
Total load P_u	= 3.14/2 x Diameter x Max load intensity
	= 3.14/2 x 4000 mm x 0.06384 KN/mm
	= 401. KN

EXAMPLE 2 : Circular Support

This example demonstrates the simulation of a circular steel set installed in weak strata which can be represented by a sinusoidal gravity load. Forty elements (41 nodes) have been employed to discretize half of the support The steel cross-section used is the same as in Example 1 and the support has a diameter of 4m. The datafile for this case is shown in Fig.1.10. From the output of the program (Fig.1.11), it can be seen that:

Max. Load Level = 8.40 x Reference Load

whereas

Reference Load = 0.011 x Initial Load

= 0.011 x 1.00 KN/mm

= 0.011 KN/mm

Thus,

Max. Load Level = 8.40 x .011 = 0.0924 KN/mm

= 92.4 KN/mm

Using the roof load formula for sinusoidal load [3] to obtain the total load, one obtains

P_U = 92.4 KN/m x Diameter

= 92.4 x 4.00 = 370 KN

It is also found from the output that there has been 16 load increments before collapse of the steel set was detected. By load increment No.16, 18 elements have yielded. These are:

Elements 1 to 6, Elements 21 to 30, Elements 39 and 40

This pattern of yielding suggets that the support failure is due to plastic instability and that 3 plastic hinges at the crown, the middle and the floor of the steel support have been formed, see Fig.11.

EXAMPLE 3: Semicircular Support with Vertical Legs

The third example is of a D-type support subject to crown concentrated load. The diameter and section properties remain as before and the leg height is 1.33m giving a leg-to-overall height ratio of 0.4. As can be seen from the datafile (Fig.1.13), an initial concentrated load of 1.0 KN is specified at the crown point (node 1). The nonlinear analysis stopped after 14 load incrament at a load level of 7.6 x Reference Load. From the output of Fig.1.14, the Reference Load = 1.0 x 5.1906 = 5.1906 KN.

The load bearing capacity of the support is given by:

$$P_U = 2\ (7.6 \times 5.1906) = 79\ KN$$

In the above, the factor 2 is used to calculate the strength of the whole support (since only half of it was modelled). Again yielding of 10 elements at 2 locations is detected indicating plastic instability failure., see Fig. 1.15.

EXAMPLE 4: Splay-Legged Support

The last example is intended to demonstrate two new features in Program S4. These are pressure loading and variable extent of loaded length of crown. An initial uniform pressure of 1.0 KN/mm is applied over 50% of the projected crown length of an A-type steel set whose legs are splayed at 15%. The diameter, section size and strength properties, and the leg-to overall height ratio are kept the same as before. The datafile is shown in Fig.1.16 whereas parts of the output file are given in Fig.1.17. The results of the analysis are as folows:

Reference pressure = 1.0 KN/mm x 0.011 (Fig.15) = 0.011 KN/mm

Max. Pressure = 0.011 KN/mm x 5.00 (Fig.15) = 0.055 KN/mm

= 55 N/mm

Max Bearing Pressure = Max Pressure /Flange width

=55 / 102 = 0.54 MPa

It is worth noting from Fig.1.18 that only elements No.1,2 and 3 have partially yielded, prior to the end of the nonlinear analysis. These are not sufficient to cause a plastic failure mechanism, thus indicating that failure in this case is due to loss of stability early in the plastic range or "inelastic buckling".

```
EXAMPLE 1:  SEMICIRCULAR SUPPORT   UNDER UNIFORM LOAD
  1  3  19  18   1  1  1
  4000 2000 90
  1  102  10.3  81.4  9.5
  0
  100
  200  0  .268  .430
```

Fig. 1.8 : Datafile of example 1

```
.113844E-01    -.262726E+01
.200000E+01    -.549012E+01
.300000E+01    -.845147E+01
.380000E+01    -.109391E+02
.460000E+01    -.135246E+02
.540000E+01    -.183910E+02
.560000E+01    -.210354E+02
```

Fig. 1.9(a) : The .PDE file

```
*************************          PROGRAM  S4          ****************
************   NONLINEAR ANALYSIS OF STEEL SET SUPPOT SYSTEMS    ****
                                    BY
**************            H.S. MITRI AND F.P. HASSANI            ********
*****************              MCGILL UNIVERSITY                ***********
*****************           MONTREAL, QUEBEC, 1989              **********
********************************************************************************
DSS CONTRACT NO. 63SS.23440-7-9054
********************************************************************************



PROBLEM TITLE : EXAMPLE 1:  SEMICIRCULAR SUPPORT   UNDER
                UNIFORM LOAD
STRUCTURE TYPE    =SEMICIRCLE
LOAD TYPE         =UNIFORM LOAD
NUMBER OF SECTIONS=    1

GEOMETRY OF THE STRUCTURE

DIAMETER   = 4000.0000
HEIGHT     = 2000.0000
SPLAY ANGLE=   90.0000
*************************     NODAL POINT DATA     ******************

NODE       X-COORD  Y-COORD     DEGREES OF FREEDOM
NUMBER                          X-DIR   Y-DIR   ROTATION


  1        .0000   2000.0000   FIXED   FREE    FIXED
  2     174.3115   1992.3894   FREE    FREE    FREE
  3     347.2964   1969.6155   FREE    FREE    FREE
  4     517.6381   1931.8516   FREE    FREE    FREE
  5     684.0403   1879.3852   FREE    FREE    FREE
  6     845.2365   1812.6156   FREE    FREE    FREE
  7    1000.0000   1732.0508   FREE    FREE    FREE
  8    1147.1529   1638.3041   FREE    FREE    FREE
  9    1285.5752   1532.0889   FREE    FREE    FREE
 10    1414.2136   1414.2135   FREE    FREE    FREE
 11    1532.0889   1285.5752   FREE    FREE    FREE
 12    1638.3041   1147.1528   FREE    FREE    FREE
 13    1732.0508    999.9999   FREE    FREE    FREE
 14    1812.6156    845.2365   FREE    FREE    FREE
 15    1879.3853    684.0402   FREE    FREE    FREE
 16    1931.8517    517.6380   FREE    FREE    FREE
 17    1969.6155    347.2963   FREE    FREE    FREE
 18    1992.3894    174.3114   FREE    FREE    FREE
 19    2000.0000      -.0001   FIXED   FIXED   FREE
********************************************************************************
```

Fig. 1.9(b) : The .DOC file

********** ELEMENT DATA **********

ELEMENT NUMBER	CONNECTING NODES		IT	IS	FLANGE WIDTH	FLANGE THICKNESS	WEB DEPTH	WEB THICKNES
1	1	2	2	1	102.000	10.300	81.400	9.5
2	2	3	2	1	102.000	10.300	81.400	9.5
3	3	4	2	1	102.000	10.300	81.400	9.5
4	4	5	2	1	102.000	10.300	81.400	9.5
5	5	6	2	1	102.000	10.300	81.400	9.5
6	6	7	2	1	102.000	10.300	81.400	9.5
7	7	8	2	1	102.000	10.300	81.400	9.5
8	8	9	2	1	102.000	10.300	81.400	9.5
9	9	10	2	1	102.000	10.300	81.400	9.5
10	10	11	2	1	102.000	10.300	81.400	9.5
11	11	12	2	1	102.000	10.300	81.400	9.5
12	12	13	2	1	102.000	10.300	81.400	9.5
13	13	14	2	1	102.000	10.300	81.400	9.5
14	14	15	2	1	102.000	10.300	81.400	9.5
15	15	16	2	1	102.000	10.300	81.400	9.5
16	16	17	2	1	102.000	10.300	81.400	9.5
17	17	18	2	1	102.000	10.300	81.400	9.5
18	18	19	2	1	102.000	10.300	81.400	9.5

****

********** INITIAL LOAD DATA **********

NO. OF NODES UNDER CONCENTRATED LOAD = 0

% LOADED OF PROJECTED CROWN LENGTH = 100

ELEMENT NUMBER	DISTRIBUTED LOADS X-DIR	Y-DIR
1	.0000	-1.0000
2	.0000	-1.0000
3	.0000	-1.0000
4	.0000	-1.0000
5	.0000	-1.0000
6	.0000	-1.0000
7	.0000	-1.0000
8	.0000	-1.0000
9	.0000	-1.0000
10	.0000	-1.0000
11	.0000	-1.0000
12	.0000	-1.0000
13	.0000	-1.0000
14	.0000	-1.0000
15	.0000	-1.0000
16	.0000	-1.0000
17	.0000	-1.0000
18	.0000	-1.0000

****

```
**************************     MATERIAL PROPERTIES     ***************
MODULUS OF ELASTICITY =   200.000   TANGENT MODULUS        =       .0
YIELD STRESS          =      .268   ULTIMATE STRESS       =       .4

*****************************************************************************

*****************     SOLUTION FOR LOAD INCREMENT NO.1     *********

REFERENCE LOAD    =     .0114 X  INITIAL LOAD


NODAL DISPLACEMENTS

NODE        X-DIR          Y-DIR          ROT

    1     .00000E+00    -.26273E+01     .00000E+00
    2    -.12727E-02    -.25769E+01     .57390E-03
    3     .14551E-01    -.24295E+01     .11171E-02
    4     .62472E-01    -.21962E+01     .16000E-02
    5     .15347E+00    -.18945E+01     .19953E-02
    6     .29296E+00    -.15467E+01     .22795E-02
    7     .47964E+00    -.11781E+01     .24332E-02
    8     .70513E+00    -.81482E+00     .24429E-02
    9     .95407E+00    -.48136E+00     .23013E-02
   10     .12051E+01    -.19848E+00     .20089E-02
   11     .14326E+01     .18849E-01     .15738E-02
   12     .16086E+01     .16291E+00     .10133E-02
   13     .17061E+01     .23413E+00     .35363E-03
   14     .17016E+01     .24114E+00    -.36921E-03
   15     .15789E+01     .19990E+00    -.11094E-02
   16     .13322E+01     .13192E+00    -.18112E-02
   17     .96861E+00     .61434E-01    -.24089E-02
   18     .51121E+00     .11619E-01    -.28272E-02
   19     .00000E+00     .00000E+00    -.29815E-02


*****************     SOLUTION FOR LOAD INCREMENT NO. 2     ********

LOAD INCREMENT =   1.00
***  CONVERGENCE  ***
AFTER  4 ITERATIONS, TOLERENCE =  .26602E-05

LOAD LEVEL    =      2.00000 X  REFERENCE LOAD
```

NODAL DISPLACEMENTS

NODE	X-DIR	Y-DIR	ROT
1	.00000E+00	-.54901E+01	.00000E+00
2	-.23734E-02	-.53853E+01	.11944E-02
3	.30587E-01	-.50785E+01	.23252E-02
4	.12994E+00	-.45928E+01	.33314E-02
5	.31854E+00	-.39642E+01	.41563E-02
6	.60777E+00	-.32390E+01	.47506E-02
7	.99530E+00	-.24697E+01	.50738E-02
8	.14639E+01	-.17109E+01	.50970E-02
9	.19821E+01	-.10138E+01	.48048E-02
10	.25054E+01	-.42210E+00	.41969E-02
11	.29803E+01	.32624E-01	.32905E-02
12	.33485E+01	.33399E+00	.21209E-02
13	.35530E+01	.48278E+00	.74351E-03
14	.35447E+01	.49716E+00	-.76602E-03
15	.32896E+01	.41087E+00	-.23111E-02
16	.27754E+01	.26931E+00	-.37745E-02
17	.20176E+01	.12342E+00	-.50189E-02
18	.10646E+01	.21607E-01	-.58878E-02
19	.00000E+00	.00000E+00	-.62078E-02

*** NO. OF YIELDING ELEMENTS = 0

********** SOLUTION FOR LOAD INCREMENT NO. 3 ********

LOAD INCREMENT = 1.00
*** CONVERGENCE ***
AFTER 3 ITERATIONS, TOLERENCE = .90343E-03

LOAD LEVEL = 3.00000 X REFERENCE LOAD

NODAL DISPLACEMENTS

NODE	X-DIR	Y-DIR	ROT
1	.00000E+00	-.84515E+01	.00000E+00
2	-.34659E-02	-.82909E+01	.18289E-02
3	.46676E-01	-.78211E+01	.35609E-02
4	.19763E+00	-.70769E+01	.51027E-02
5	.48431E+00	-.61133E+01	.63678E-02
6	.92436E+00	-.50007E+01	.72804E-02
7	.15146E+01	-.38198E+01	.77784E-02
8	.22295E+01	-.26538E+01	.78172E-02
9	.30210E+01	-.15819E+01	.73725E-02
10	.38217E+01	-.67150E+00	.64435E-02
11	.45496E+01	.28487E-01	.50561E-02

```
  12      .51152E+01      .49253E+00      .32644E-02
  13      .54307E+01      .72177E+00      .11533E-02
  14      .54204E+01      .74444E+00     -.11606E-02
  15      .50316E+01      .61296E+00     -.35286E-02
  16      .42454E+01      .39779E+00     -.57704E-02
  17      .30861E+01      .17766E+00     -.76750E-02
  18      .16281E+01      .26849E-01     -.90036E-02
  19      .00000E+00      .00000E+00     -.94924E-02
***  NO. OF YIELDING ELEMENTS =    0


*****************      SOLUTION FOR LOAD INCREMENT NO. 4      ********

LOAD INCREMENT =     .80
***  CONVERGENCE  ***
AFTER  4 ITERATIONS, TOLERENCE =  .89790E-05

LOAD LEVEL   =       3.80000 X  REFERENCE LOAD


NODAL DISPLACEMENTS

NODE         X-DIR           Y-DIR           ROT

   1      .00000E+00     -.10939E+02      .00000E+00
   2     -.42755E-02     -.10732E+02      .23579E-02
   3      .60091E-01     -.10126E+02      .45914E-02
   4      .25363E+00     -.91665E+01      .65803E-02
   5      .62127E+00     -.79230E+01      .82134E-02
   6      .11860E+01     -.64866E+01      .93928E-02
   7      .19441E+01     -.49610E+01      .10038E-01
   8      .28632E+01     -.34538E+01      .10092E-01
   9      .38820E+01     -.20674E+01      .95212E-02
  10      .49140E+01     -.88918E+00      .83253E-02
  11      .58533E+01      .16965E-01      .65368E-02
  12      .65845E+01      .61779E+00      .42256E-02
  13      .69937E+01      .91471E+00      .15013E-02
  14      .69827E+01      .94447E+00     -.14851E-02
  15      .64830E+01      .77545E+00     -.45409E-02
  16      .54704E+01      .49938E+00     -.74325E-02
  17      .39764E+01      .21852E+00     -.98875E-02
  18      .20975E+01      .28796E-01     -.11599E-01
  19      .00000E+00      .00000E+00     -.12228E-01
***  NO. OF YIELDING ELEMENTS =    0


*****************      SOLUTION FOR LOAD INCREMENT NO. 5      ********

LOAD INCREMENT =     .80
***  CONVERGENCE  ***
```

AFTER 4 ITERATIONS, TOLERENCE = .19436E-04

LOAD LEVEL = 4.60000 X REFERENCE LOAD

NODAL DISPLACEMENTS

NODE	X-DIR	Y-DIR	ROT
1	.00000E+00	-.13525E+02	.00000E+00
2	-.50400E-02	-.13270E+02	.29041E-02
3	.73888E-01	-.12524E+02	.56553E-02
4	.31094E+00	-.11341E+02	.81062E-02
5	.76133E+00	-.98082E+01	.10120E-01
6	.14536E+01	-.80367E+01	.11576E-01
7	.23838E+01	-.61540E+01	.12375E-01
8	.35126E+01	-.42929E+01	.12445E-01
9	.47654E+01	-.25800E+01	.11746E-01
10	.60358E+01	-.11237E+01	.10275E-01
11	.71939E+01	-.31960E-02	.80729E-02
12	.80967E+01	.73991E+00	.52250E-02
13	.86036E+01	.11073E+01	.18668E-02
14	.85928E+01	.11447E+01	-.18150E-02
15	.79794E+01	.93709E+00	-.55822E-02
16	.67335E+01	.59873E+00	-.91452E-02
17	.48942E+01	.25640E+00	-.12168E-01
18	.25813E+01	.28435E-01	-.14273E-01
19	.00000E+00	.00000E+00	-.15046E-01

***** YIELDING OF ELEMENT NO. 14 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.13452E-02
2	.1127	-.3333	-.24669E+00	-.12335E-02
3	.1127	-.1667	-.22433E+00	-.11217E-02
4	.1127	.0000	-.47654E-01	-.23827E-03
5	.1127	.1667	.12903E+00	.64513E-03
6	.1127	.3333	.15138E+00	.75691E-03
7	.1127	.5000	.17374E+00	.86869E-03
8	.5000	-.5000	-.26693E+00	-.13347E-02
9	.5000	-.3333	-.24469E+00	-.12235E-02
10	.5000	-.1667	-.22245E+00	-.11123E-02
11	.5000	.0000	-.46698E-01	-.23349E-03
12	.5000	.1667	.12906E+00	.64529E-03
13	.5000	.3333	.15130E+00	.75648E-03
14	.5000	.5000	.17354E+00	.86768E-03
15	.8873	-.5000	-.26436E+00	-.13218E-02
16	.8873	-.3333	-.24223E+00	-.12112E-02
17	.8873	-.1667	-.22011E+00	-.11006E-02
18	.8873	.0000	-.45280E-01	-.22640E-03
19	.8873	.1667	.12955E+00	.64776E-03

```
   20    .8873    .3333   .15167E+00        .75837E-03
   21    .8873    .5000   .17380E+00        .86898E-03
*****  YIELDING OF ELEMENT NO.     15  *****

POINT    X-CRD    Y-CRD     STRESS          STRAIN

    1    .1127   -.5000  -.26800E+00       -.13401E-02
    2    .1127   -.3333  -.24617E+00       -.12308E-02
    3    .1127   -.1667  -.22431E+00       -.11215E-02
    4    .1127    .0000  -.51535E-01       -.25768E-03
    5    .1127    .1667   .12124E+00        .60618E-03
    6    .1127    .3333   .14310E+00        .71549E-03
    7    .1127    .5000   .16496E+00        .82480E-03
    8    .5000   -.5000  -.25775E+00       -.12887E-02
    9    .5000   -.3333  -.23672E+00       -.11836E-02
   10    .5000   -.1667  -.21568E+00       -.10784E-02
   11    .5000    .0000  -.49460E-01       -.24730E-03
   12    .5000    .1667   .11676E+00        .58382E-03
   13    .5000    .3333   .13780E+00        .68899E-03
   14    .5000    .5000   .15883E+00        .79415E-03
   15    .8873   -.5000  -.24714E+00       -.12357E-02
   16    .8873   -.3333  -.22694E+00       -.11347E-02
   17    .8873   -.1667  -.20673E+00       -.10337E-02
   18    .8873    .0000  -.47054E-01       -.23527E-03
   19    .8873    .1667   .11262E+00        .56311E-03
   20    .8873    .3333   .13283E+00        .66414E-03
   21    .8873    .5000   .15303E+00        .76516E-03
***  NO. OF YIELDING ELEMENTS =   2


*****************      SOLUTION FOR LOAD INCREMENT NO. 6      ********

LOAD INCREMENT =     .80
***  CONVERGENCE  ***
AFTER  6 ITERATIONS, TOLERENCE =  .75403E-03

LOAD LEVEL   =       5.40000 X  REFERENCE LOAD


NODAL DISPLACEMENTS

NODE         X-DIR           Y-DIR          ROT

   1      .00000E+00     -.18391E+02      .00000E+00
   2     -.46564E-02     -.18064E+02      .37238E-02
   3      .97389E-01     -.17107E+02      .72629E-02
   4      .40114E+00     -.15586E+02      .10439E-01
   5      .97895E+00     -.13607E+02      .13085E-01
   6      .18711E+01     -.11308E+02      .15054E-01
   7      .30788E+01     -.88466E+01      .16225E-01
   8      .45597E+01     -.63886E+01      .16507E-01
```

9	.62283E+01	-.40937E+01	.15849E-01
10	.79591E+01	-.21008E+01	.14243E-01
11	.95960E+01	-.51445E+00	.11732E-01
12	.10965E+02	.60619E+00	.84159E-02
13	.11891E+02	.12550E+01	.44189E-02
14	.12109E+02	.14696E+01	-.11722E-02
15	.11317E+02	.12892E+01	-.79740E-02
16	.94705E+01	.83340E+00	-.13602E-01
17	.68050E+01	.34015E+00	-.17277E-01
18	.35641E+01	.28275E-01	-.19800E-01
19	.00000E+00	.00000E+00	-.20725E-01

***** YIELDING OF ELEMENT NO. 12 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26521E+00	-.13260E-02
2	.1127	-.3333	-.24312E+00	-.12156E-02
3	.1127	-.1667	-.22104E+00	-.11052E-02
4	.1127	.0000	-.46498E-01	-.23249E-03
5	.1127	.1667	.12804E+00	.64020E-03
6	.1127	.3333	.15013E+00	.75063E-03
7	.1127	.5000	.17221E+00	.86105E-03
8	.5000	-.5000	-.26800E+00	-.14124E-02
9	.5000	-.3333	-.25888E+00	-.12944E-02
10	.5000	-.1667	-.23529E+00	-.11764E-02
11	.5000	.0000	-.48812E-01	-.24406E-03
12	.5000	.1667	.13766E+00	.68831E-03
13	.5000	.3333	.16126E+00	.80629E-03
14	.5000	.5000	.18485E+00	.92427E-03
15	.8873	-.5000	-.26800E+00	-.14968E-02
16	.8873	-.3333	-.26800E+00	-.13713E-02
17	.8873	-.1667	-.24915E+00	-.12458E-02
18	.8873	.0000	-.50741E-01	-.25370E-03
19	.8873	.1667	.14767E+00	.73836E-03
20	.8873	.3333	.17278E+00	.86389E-03
21	.8873	.5000	.19788E+00	.98942E-03

***** YIELDING OF ELEMENT NO. 13 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.20691E-02
2	.1127	-.3333	-.26800E+00	-.19112E-02
3	.1127	-.1667	-.26800E+00	-.17532E-02
4	.1127	.0000	-.10103E+00	-.50515E-03
5	.1127	.1667	.14859E+00	.74293E-03
6	.1127	.3333	.18017E+00	.90086E-03
7	.1127	.5000	.21176E+00	.10588E-02
8	.5000	-.5000	-.26800E+00	-.21457E-02
9	.5000	-.3333	-.26800E+00	-.19807E-02
10	.5000	-.1667	-.26800E+00	-.18156E-02
11	.5000	.0000	-.10228E+00	-.51142E-03
12	.5000	.1667	.15856E+00	.79281E-03

13	.5000	.3333	.19157E+00	.95784E-03
14	.5000	.5000	.22457E+00	.11229E-02
15	.8873	-.5000	-.26800E+00	-.22175E-02
16	.8873	-.3333	-.26800E+00	-.20454E-02
17	.8873	-.1667	-.26800E+00	-.18732E-02
18	.8873	.0000	-.10257E+00	-.51284E-03
19	.8873	.1667	.16951E+00	.84753E-03
20	.8873	.3333	.20393E+00	.10197E-02
21	.8873	.5000	.23836E+00	.11918E-02

***** YIELDING OF ELEMENT NO. 14 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.27819E-02
2	.1127	-.3333	-.26800E+00	-.25788E-02
3	.1127	-.1667	-.26800E+00	-.23756E-02
4	.1127	.0000	-.15403E+00	-.77015E-03
5	.1127	.1667	.16706E+00	.83532E-03
6	.1127	.3333	.20769E+00	.10385E-02
7	.1127	.5000	.24832E+00	.12416E-02
8	.5000	-.5000	-.26800E+00	-.27491E-02
9	.5000	-.3333	-.26800E+00	-.25484E-02
10	.5000	-.1667	-.26800E+00	-.23476E-02
11	.5000	.0000	-.15219E+00	-.76097E-03
12	.5000	.1667	.16514E+00	.82568E-03
13	.5000	.3333	.20529E+00	.10265E-02
14	.5000	.5000	.24544E+00	.12272E-02
15	.8873	-.5000	-.26800E+00	-.27090E-02
16	.8873	-.3333	-.26800E+00	-.25106E-02
17	.8873	-.1667	-.26800E+00	-.23122E-02
18	.8873	.0000	-.14888E+00	-.74439E-03
19	.8873	.1667	.16469E+00	.82344E-03
20	.8873	.3333	.20436E+00	.10218E-02
21	.8873	.5000	.24404E+00	.12202E-02

***** YIELDING OF ELEMENT NO. 15 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.23714E-02
2	.1127	-.3333	-.26800E+00	-.21925E-02
3	.1127	-.1667	-.26800E+00	-.20136E-02
4	.1127	.0000	-.11991E+00	-.59955E-03
5	.1127	.1667	.16289E+00	.81446E-03
6	.1127	.3333	.19868E+00	.99339E-03
7	.1127	.5000	.23446E+00	.11723E-02
8	.5000	-.5000	-.26800E+00	-.22210E-02
9	.5000	-.3333	-.26800E+00	-.20549E-02
10	.5000	-.1667	-.26800E+00	-.18887E-02
11	.5000	.0000	-.11516E+00	-.57580E-03
12	.5000	.1667	.14742E+00	.73712E-03
13	.5000	.3333	.18065E+00	.90325E-03
14	.5000	.5000	.21388E+00	.10694E-02

```
   15    .8873   -.5000 -.26800E+00       -.20674E-02
   16    .8873   -.3333 -.26800E+00       -.19141E-02
   17    .8873   -.1667 -.26800E+00       -.17608E-02
   18    .8873    .0000 -.10979E+00       -.54894E-03
   19    .8873    .1667  .13258E+00        .66288E-03
   20    .8873    .3333  .16324E+00        .81622E-03
   21    .8873    .5000  .19391E+00        .96956E-03
*****  YIELDING OF ELEMENT NO.    16  *****

POINT    X-CRD    Y-CRD     STRESS          STRAIN

    1    .1127   -.5000 -.26800E+00       -.15309E-02
    2    .1127   -.3333 -.26800E+00       -.14104E-02
    3    .1127   -.1667 -.25798E+00       -.12899E-02
    4    .1127    .0000 -.67502E-01       -.33751E-03
    5    .1127    .1667  .12298E+00        .61489E-03
    6    .1127    .3333  .14708E+00        .73540E-03
    7    .1127    .5000  .17118E+00        .85591E-03
    8    .5000   -.5000 -.26800E+00       -.13877E-02
    9    .5000   -.3333 -.25584E+00       -.12792E-02
   10    .5000   -.1667 -.23415E+00       -.11708E-02
   11    .5000    .0000 -.62717E-01       -.31359E-03
   12    .5000    .1667  .10872E+00        .54358E-03
   13    .5000    .3333  .13041E+00        .65204E-03
   14    .5000    .5000  .15210E+00        .76051E-03
   15    .8873   -.5000 -.24897E+00       -.12448E-02
   16    .8873   -.3333 -.22969E+00       -.11484E-02
   17    .8873   -.1667 -.21040E+00       -.10520E-02
   18    .8873    .0000 -.58016E-01       -.29008E-03
   19    .8873    .1667  .94371E-01        .47186E-03
   20    .8873    .3333  .11365E+00        .56827E-03
   21    .8873    .5000  .13294E+00        .66468E-03
***  NO. OF YIELDING ELEMENTS =   5


*****************     SOLUTION FOR LOAD INCREMENT NO. 7     ********

LOAD INCREMENT =     .20
***  CONVERGENCE  ***
AFTER  6 ITERATIONS, TOLERENCE =  .40718E-03

LOAD LEVEL   =      5.60000 X  REFERENCE LOAD


NODAL DISPLACEMENTS

NODE        X-DIR          Y-DIR          ROT

   1     .00000E+00    -.21035E+02     .00000E+00
   2    -.38492E-02    -.20676E+02     .40978E-02
   3     .10927E+00    -.19622E+02     .80006E-02
```

4	.44402E+00	-.17945E+02	.11520E-01
5	.10813E+01	-.15758E+02	.14481E-01
6	.20681E+01	-.13208E+02	.16726E-01
7	.34102E+01	-.10464E+02	.18126E-01
8	.50671E+01	-.77057E+01	.18584E-01
9	.69519E+01	-.51061E+01	.18042E-01
10	.89350E+01	-.28178E+01	.16489E-01
11	.10853E+02	-.95767E+00	.13967E-01
12	.12521E+02	.40483E+00	.10576E-01
13	.13746E+02	.12562E+01	.63562E-02
14	.14134E+02	.16139E+01	-.64038E-03
15	.13273E+02	.14642E+01	-.91026E-02
16	.11084E+02	.96568E+00	-.16346E-01
17	.79120E+01	.38525E+00	-.20343E-01
18	.41261E+01	.25955E-01	-.22988E-01
19	.00000E+00	.00000E+00	-.23958E-01

***** YIELDING OF ELEMENT NO. 12 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.13822E-02
2	.1127	-.3333	-.25366E+00	-.12683E-02
3	.1127	-.1667	-.23088E+00	-.11544E-02
4	.1127	.0000	-.50869E-01	-.25434E-03
5	.1127	.1667	.12915E+00	.64573E-03
6	.1127	.3333	.15192E+00	.75962E-03
7	.1127	.5000	.17470E+00	.87351E-03
8	.5000	-.5000	-.26800E+00	-.15032E-02
9	.5000	-.3333	-.26800E+00	-.13786E-02
10	.5000	-.1667	-.25081E+00	-.12541E-02
11	.5000	.0000	-.53952E-01	-.26976E-03
12	.5000	.1667	.14291E+00	.71455E-03
13	.5000	.3333	.16782E+00	.83910E-03
14	.5000	.5000	.19273E+00	.96365E-03
15	.8873	-.5000	-.26800E+00	-.16225E-02
16	.8873	-.3333	-.26800E+00	-.14873E-02
17	.8873	-.1667	-.26800E+00	-.13521E-02
18	.8873	.0000	-.56711E-01	-.28356E-03
19	.8873	.1667	.15700E+00	.78498E-03
20	.8873	.3333	.18404E+00	.92019E-03
21	.8873	.5000	.21108E+00	.10554E-02

***** YIELDING OF ELEMENT NO. 13 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.27286E-02
2	.1127	-.3333	-.26800E+00	-.25307E-02
3	.1127	-.1667	-.26800E+00	-.23329E-02
4	.1127	.0000	-.15381E+00	-.76903E-03
5	.1127	.1667	.15896E+00	.79480E-03
6	.1127	.3333	.19854E+00	.99268E-03
7	.1127	.5000	.23811E+00	.11906E-02

8	.5000	-.5000	-.26800E+00	-.28263E-02
9	.5000	-.3333	-.26800E+00	-.26198E-02
10	.5000	-.1667	-.26800E+00	-.24133E-02
11	.5000	.0000	-.15624E+00	-.78118E-03
12	.5000	.1667	.17018E+00	.85090E-03
13	.5000	.3333	.21148E+00	.10574E-02
14	.5000	.5000	.25279E+00	.12639E-02
15	.8873	-.5000	-.26800E+00	-.29165E-02
16	.8873	-.3333	-.26800E+00	-.27014E-02
17	.8873	-.1667	-.26800E+00	-.24862E-02
18	.8873	.0000	-.15718E+00	-.78588E-03
19	.8873	.1667	.18289E+00	.91445E-03
20	.8873	.3333	.22592E+00	.11296E-02
21	.8873	.5000	.26800E+00	.13448E-02

***** YIELDING OF ELEMENT NO. 14 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.35832E-02
2	.1127	-.3333	-.26800E+00	-.33307E-02
3	.1127	-.1667	-.26800E+00	-.30783E-02
4	.1127	.0000	-.21664E+00	-.10832E-02
5	.1127	.1667	.18238E+00	.91190E-03
6	.1127	.3333	.23287E+00	.11644E-02
7	.1127	.5000	.26800E+00	.14168E-02
8	.5000	-.5000	-.26800E+00	-.35455E-02
9	.5000	-.3333	-.26800E+00	-.32957E-02
10	.5000	-.1667	-.26800E+00	-.30459E-02
11	.5000	.0000	-.21439E+00	-.10720E-02
12	.5000	.1667	.18040E+00	.90198E-03
13	.5000	.3333	.23035E+00	.11518E-02
14	.5000	.5000	.26800E+00	.14015E-02
15	.8873	-.5000	-.26800E+00	-.34964E-02
16	.8873	-.3333	-.26800E+00	-.32493E-02
17	.8873	-.1667	-.26800E+00	-.30022E-02
18	.8873	.0000	-.20988E+00	-.10494E-02
19	.8873	.1667	.18068E+00	.90341E-03
20	.8873	.3333	.23010E+00	.11505E-02
21	.8873	.5000	.26800E+00	.13976E-02

***** YIELDING OF ELEMENT NO. 15 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.31837E-02
2	.1127	-.3333	-.26800E+00	-.29553E-02
3	.1127	-.1667	-.26800E+00	-.27268E-02
4	.1127	.0000	-.18427E+00	-.92133E-03
5	.1127	.1667	.17683E+00	.88415E-03
6	.1127	.3333	.22252E+00	.11126E-02
7	.1127	.5000	.26800E+00	.13411E-02
8	.5000	-.5000	-.26800E+00	-.30033E-02
9	.5000	-.3333	-.26800E+00	-.27895E-02

10	.5000	-.1667	-.26800E+00	-.25757E-02
11	.5000	.0000	-.17722E+00	-.88609E-03
12	.5000	.1667	.16070E+00	.80352E-03
13	.5000	.3333	.20346E+00	.10173E-02
14	.5000	.5000	.24622E+00	.12311E-02
15	.8873	-.5000	-.26800E+00	-.28171E-02
16	.8873	-.3333	-.26800E+00	-.26180E-02
17	.8873	-.1667	-.26800E+00	-.24188E-02
18	.8873	.0000	-.16902E+00	-.84509E-03
19	.8873	.1667	.14573E+00	.72866E-03
20	.8873	.3333	.18556E+00	.92779E-03
21	.8873	.5000	.22539E+00	.11269E-02

***** YIELDING OF ELEMENT NO. 16 *****

POINT	X-CRD	Y-CRD	STRESS	STRAIN
1	.1127	-.5000	-.26800E+00	-.17243E-02
2	.1127	-.3333	-.26800E+00	-.15891E-02
3	.1127	-.1667	-.26800E+00	-.14538E-02
4	.1127	.0000	-.76932E-01	-.38466E-03
5	.1127	.1667	.13689E+00	.68446E-03
6	.1127	.3333	.16395E+00	.81974E-03
7	.1127	.5000	.19100E+00	.95502E-03
8	.5000	-.5000	-.26800E+00	-.15218E-02
9	.5000	-.3333	-.26800E+00	-.14038E-02
10	.5000	-.1667	-.25717E+00	-.12859E-02
11	.5000	.0000	-.70683E-01	-.35341E-03
12	.5000	.1667	.11581E+00	.57903E-03
13	.5000	.3333	.13940E+00	.69702E-03
14	.5000	.5000	.16300E+00	.81500E-03
15	.8873	-.5000	-.26423E+00	-.13212E-02
16	.8873	-.3333	-.24410E+00	-.12205E-02
17	.8873	-.1667	-.22396E+00	-.11198E-02
18	.8873	.0000	-.64803E-01	-.32401E-03
19	.8873	.1667	.94351E-01	.47176E-03
20	.8873	.3333	.11449E+00	.57245E-03
21	.8873	.5000	.13463E+00	.67314E-03

*** NO. OF YIELDING ELEMENTS = 5

********** SOLUTION FOR LOAD INCREMENT NO. 8 ********

LOAD INCREMENT = .20
SOLUTION IS DIVERGING- FAILURE IS IMMINENT
1 ********** S U M M A R Y OF R E S U L T S *****

LOAD INCR	LOAD LEVEL			NOMINAL STIFFNESS
0	.00	X	REFERENCE LOAD	.00000E+00
1	1.00	X	REFERENCE LOAD	.11453E+01
2	2.00	X	REFERENCE LOAD	.10529E+01
3	3.00	X	REFERENCE LOAD	.10231E+01
4	3.80	X	REFERENCE LOAD	.97720E+00
5	4.60	X	REFERENCE LOAD	.94213E+00
6	5.40	X	REFERENCE LOAD	.47328E+00
7	5.60	X	REFERENCE LOAD	.21082E+00
8	.00	X	REFERENCE LOAD	.00000E+00

```
EXAMPLE 2:  CIRCULAR SUPPORT UNDER SINUSOIDAL LOAD
  1  3  41  40   5  2  1
 4000 2000 90
 1  102  10.3  81.4  9.5
 0
 100
 200  0  .268  .430
```

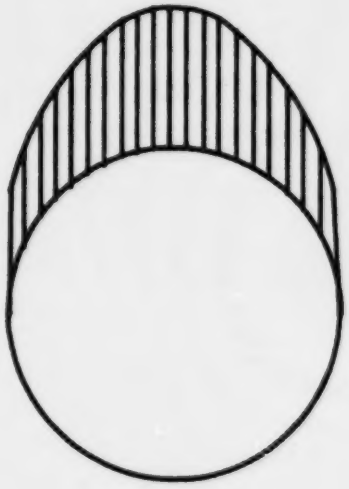


Fig. 1.10 : Datafile of example 2

```
************************          PROGRAM  S4          ****************
************   NONLINEAR ANALYSIS OF STEEL SET SUPPOT SYSTEMS    ****
                                  BY
**************           H.S. MITRI AND F.P. HASSANI            ********
*****************             MCGILL UNIVERSITY              ***********
*****************           MONTREAL, QUEBEC, 1989           **********
*************************************************************************
DSS CONTRACT NO. 63SS.23440-7-9054
*************************************************************************



PROBLEM TITLE : EXAMPLE 2:  CIRCULAR SUPPORT UNDER SINUS
                OIDAL LOAD
STRUCTURE TYPE    =CIRCLE
LOAD TYPE         =SINUSOIDAL LOAD
NUMBER OF SECTIONS=    1

GEOMETRY OF THE STRUCTURE

DIAMETER   = 4000.0000
HEIGHT     = 2000.0000
SPLAY ANGLE=   90.0000
************************     NODAL POINT DATA     *****************
```

NODE NUMBER	X-COORD	Y-COORD	DEGREES OF FREEDOM X-DIR	Y-DIR	ROTATION
1	.0000	2000.0000	FIXED	FREE	FIXED
2	78.5196	1998.4581	FREE	FREE	FREE
3	156.9182	1993.8347	FREE	FREE	FREE
4	235.0748	1986.1369	FREE	FREE	FREE
5	312.8689	1975.3767	FREE	FREE	FREE
6	390.1807	1961.5706	FREE	FREE	FREE
7	466.8907	1944.7398	FREE	FREE	FREE
8	542.8809	1924.9105	FREE	FREE	FREE
9	618.0340	1902.1130	FREE	FREE	FREE
10	692.2341	1876.3827	FREE	FREE	FREE
11	765.3669	1847.7591	FREE	FREE	FREE
12	837.3195	1816.2863	FREE	FREE	FREE
13	907.9810	1782.0130	FREE	FREE	FREE
14	977.2425	1744.9920	FREE	FREE	FREE
15	1044.9972	1705.2803	FREE	FREE	FREE
16	1111.1405	1662.9392	FREE	FREE	FREE
17	1175.5705	1618.0340	FREE	FREE	FREE
18	1238.1879	1570.6338	FREE	FREE	FREE
19	1298.8961	1520.8119	FREE	FREE	FREE
20	1357.6015	1468.6450	FREE	FREE	FREE
21	1414.2136	1414.2135	FREE	FREE	FREE
22	1468.6451	1357.6015	FREE	FREE	FREE

Fig. 1.11 : Output file of example 2

23	1520.8120	1298.8961	FREE	FREE	FREE
24	1570.6339	1238.1879	FREE	FREE	FREE
25	1618.0340	1175.5705	FREE	FREE	FREE
26	1662.9393	1111.1404	FREE	FREE	FREE
27	1705.2804	1044.9971	FREE	FREE	FREE
28	1744.9920	977.2424	FREE	FREE	FREE
29	1782.0131	907.9809	FREE	FREE	FREE
30	1816.2864	837.3194	FREE	FREE	FREE
31	1847.7591	765.3668	FREE	FREE	FREE
32	1876.3827	692.2341	FREE	FREE	FREE
33	1902.1131	618.0339	FREE	FREE	FREE
34	1924.9105	542.8808	FREE	FREE	FREE
35	1944.7399	466.8907	FREE	FREE	FREE
36	1961.5706	390.1806	FREE	FREE	FREE
37	1975.3767	312.8689	FREE	FREE	FREE
38	1986.1369	235.0747	FREE	FREE	FREE
39	1993.8347	156.9181	FREE	FREE	FREE
40	1998.4581	78.5195	FREE	FREE	FREE
41	2000.0000	-.0001	FIXED	FIXED	FIXED

****

********** ELEMENT DATA **********

ELEMENT NUMBER	CONNECTING NODES		IT	IS	FLANGE WIDTH	THICKNESS	WEB DEPTH	THICKNES
1	1	2	2	1	102.000	10.300	81.400	9.5
2	2	3	2	1	102.000	10.300	81.400	9.5
3	3	4	2	1	102.000	10.300	81.400	9.5
4	4	5	2	1	102.000	10.300	81.400	9.5
5	5	6	2	1	102.000	10.300	81.400	9.5
6	6	7	2	1	102.000	10.300	81.400	9.5
7	7	8	2	1	102.000	10.300	81.400	9.5
8	8	9	2	1	102.000	10.300	81.400	9.5
9	9	10	2	1	102.000	10.300	81.400	9.5
10	10	11	2	1	102.000	10.300	81.400	9.5
11	11	12	2	1	102.000	10.300	81.400	9.5
12	12	13	2	1	102.000	10.300	81.400	9.5
13	13	14	2	1	102.000	10.300	81.400	9.5
14	14	15	2	1	102.000	10.300	81.400	9.5
15	15	16	2	1	102.000	10.300	81.400	9.5
16	16	17	2	1	102.000	10.300	81.400	9.5
17	17	18	2	1	102.000	10.300	81.400	9.5
18	18	19	2	1	102.000	10.300	81.400	9.5
19	19	20	2	1	102.000	10.300	81.400	9.5
20	20	21	2	1	102.000	10.300	81.400	9.5
21	21	22	2	1	102.000	10.300	81.400	9.5
22	22	23	2	1	102.000	10.300	81.400	9.5
23	23	24	2	1	102.000	10.300	81.400	9.5
24	24	25	2	1	102.000	10.300	81.400	9.5
25	25	26	2	1	102.000	10.300	81.400	9.5

26	26	27	2	1	102.000	10.300	81.400	9.5
27	27	28	2	1	102.000	10.300	81.400	9.5
28	28	29	2	1	102.000	10.300	81.400	9.5
29	29	30	2	1	102.000	10.300	81.400	9.5
30	30	31	2	1	102.000	10.300	81.400	9.5
31	31	32	2	1	102.000	10.300	81.400	9.5
32	32	33	2	1	102.000	10.300	81.400	9.5
33	33	34	2	1	102.000	10.300	81.400	9.5
34	34	35	2	1	102.000	10.300	81.400	9.5
35	35	36	2	1	102.000	10.300	81.400	9.5
36	36	37	2	1	102.000	10.300	81.400	9.5
37	37	38	2	1	102.000	10.300	81.400	9.5
38	38	39	2	1	102.000	10.300	81.400	9.5
39	39	40	2	1	102.000	10.300	81.400	9.5
40	40	41	2	1	102.000	10.300	81.400	9.5

****

********** INITIAL LOAD DATA **********

NO. OF NODES UNDER CONCENTRATED LOAD = 0

% LOADED OF PROJECTED CROWN LENGTH = 100

ELEMENT NUMBER	DISTRIBUTED LOADS X-DIR	Y-DIR
1	.0000	-.9996
2	.0000	-.9981
3	.0000	-.9950
4	.0000	-.9904
5	.0000	-.9842
6	.0000	-.9766
7	.0000	-.9674
8	.0000	-.9568
9	.0000	-.9446
10	.0000	-.9310
11	.0000	-.9160
12	.0000	-.8996
13	.0000	-.8818
14	.0000	-.8626
15	.0000	-.8421
16	.0000	-.8202
17	.0000	-.7972
18	.0000	-.7729
19	.0000	-.7474
20	.0000	-.7207

****

********** MATERIAL PROPERTIES **********

MODULUS OF ELASTICITY = 200.000 TANGENT MODULUS = .000

YIELD STRESS = .268 ULTIMATE STRESS = .430

****

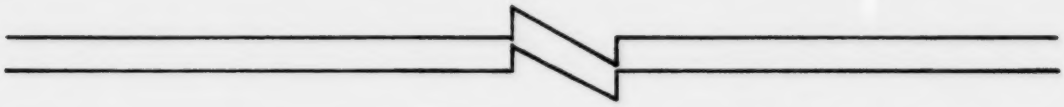
********** SOLUTION FOR LOAD INCREMENT NO.1 **********

REFERENCE LOAD = .0110 X INITIAL LOAD

NODAL DISPLACEMENTS

NODE	X-DIR	Y-DIR	ROT
1	.00000E+00	-.14885E+01	.00000E+00
2	-.13883E-02	-.14810E+01	.18841E-03
3	-.16246E-02	-.14589E+01	.37415E-03
4	.40704E-03	-.14224E+01	.55458E-03
5	.57506E-02	-.13722E+01	.72711E-03
6	.15345E-01	-.13094E+01	.88925E-03
7	.29990E-01	-.12350E+01	.10386E-02
8	.50323E-01	-.11505E+01	.11730E-02
9	.76788E-01	-.10573E+01	.12902E-02
10	.10962E+00	-.95721E+00	.13885E-02
11	.14883E+00	-.85203E+00	.14662E-02
12	.19418E+00	-.74363E+00	.15219E-02
13	.24521E+00	-.63396E+00	.15544E-02
14	.30121E+00	-.52491E+00	.15628E-02
15	.36123E+00	-.41837E+00	.15467E-02
16	.42411E+00	-.31612E+00	.15056E-02
17	.48850E+00	-.21983E+00	.14397E-02
18	.55285E+00	-.13098E+00	.13494E-02
19	.61548E+00	-.50882E-01	.12354E-02
20	.67462E+00	.19384E-01	.10988E-02
21	.72839E+00	.78989E-01	.94113E-03
22	.77496E+00	.12736E+00	.76451E-03
23	.81255E+00	.16425E+00	.57324E-03
24	.83962E+00	.18985E+00	.37207E-03
25	.85490E+00	.20470E+00	.16576E-03
26	.85741E+00	.20964E+00	-.40906E-04
27	.84657E+00	.20581E+00	-.24317E-03
28	.82217E+00	.19453E+00	-.43625E-03
29	.78443E+00	.17730E+00	-.61541E-03
30	.73403E+00	.15572E+00	-.77591E-03
31	.67208E+00	.13142E+00	-.91304E-03
32	.60021E+00	.10601E+00	-.10222E-02
33	.52049E+00	.81023E-01	-.10986E-02

34	.43549E+00	.57825E-01	-.11378E-02
35	.34822E+00	.37577E-01	-.11353E-02
36	.26217E+00	.21158E-01	-.10867E-02
37	.18124E+00	.91027E-02	-.98741E-03
38	.10974E+00	.15479E-02	-.83329E-03
39	.52321E-01	-.18324E-02	-.62008E-03
40	.13987E-01	-.18790E-02	-.34366E-03
41	.00000E+00	.00000E+00	.00000E+00



********** SOLUTION FOR LOAD INCREMENT NO.17 ********

LOAD INCREMENT = .20
SOLUTION IS DIVERGING- FAILURE IS IMMINENT
********** S U M M A R Y OF R E S U L T S ******

LOAD INCR	LOAD LEVEL			NOMINAL STIFFNESS
0	.00	X	REFERENCE LOAD	.00000E+00
1	1.00	X	REFERENCE LOAD	.63413E+00
2	2.00	X	REFERENCE LOAD	.61180E+00
3	3.00	X	REFERENCE LOAD	.61090E+00
4	4.00	X	REFERENCE LOAD	.59581E+00
5	5.00	X	REFERENCE LOAD	.58411E+00
6	6.00	X	REFERENCE LOAD	.50391E+00
7	6.60	X	REFERENCE LOAD	.36713E+00
8	6.80	X	REFERENCE LOAD	.31123E+00
9	7.00	X	REFERENCE LOAD	.27898E+00
10	7.20	X	REFERENCE LOAD	.27550E+00
11	7.40	X	REFERENCE LOAD	.26803E+00
12	7.60	X	REFERENCE LOAD	.25528E+00
13	7.80	X	REFERENCE LOAD	.18245E+00
14	8.00	X	REFERENCE LOAD	.11949E+00
15	8.20	X	REFERENCE LOAD	.95312E-01
16	8.40	X	REFERENCE LOAD	.50077E-01
17	.00	X	REFERENCE LOAD	.00000E+00

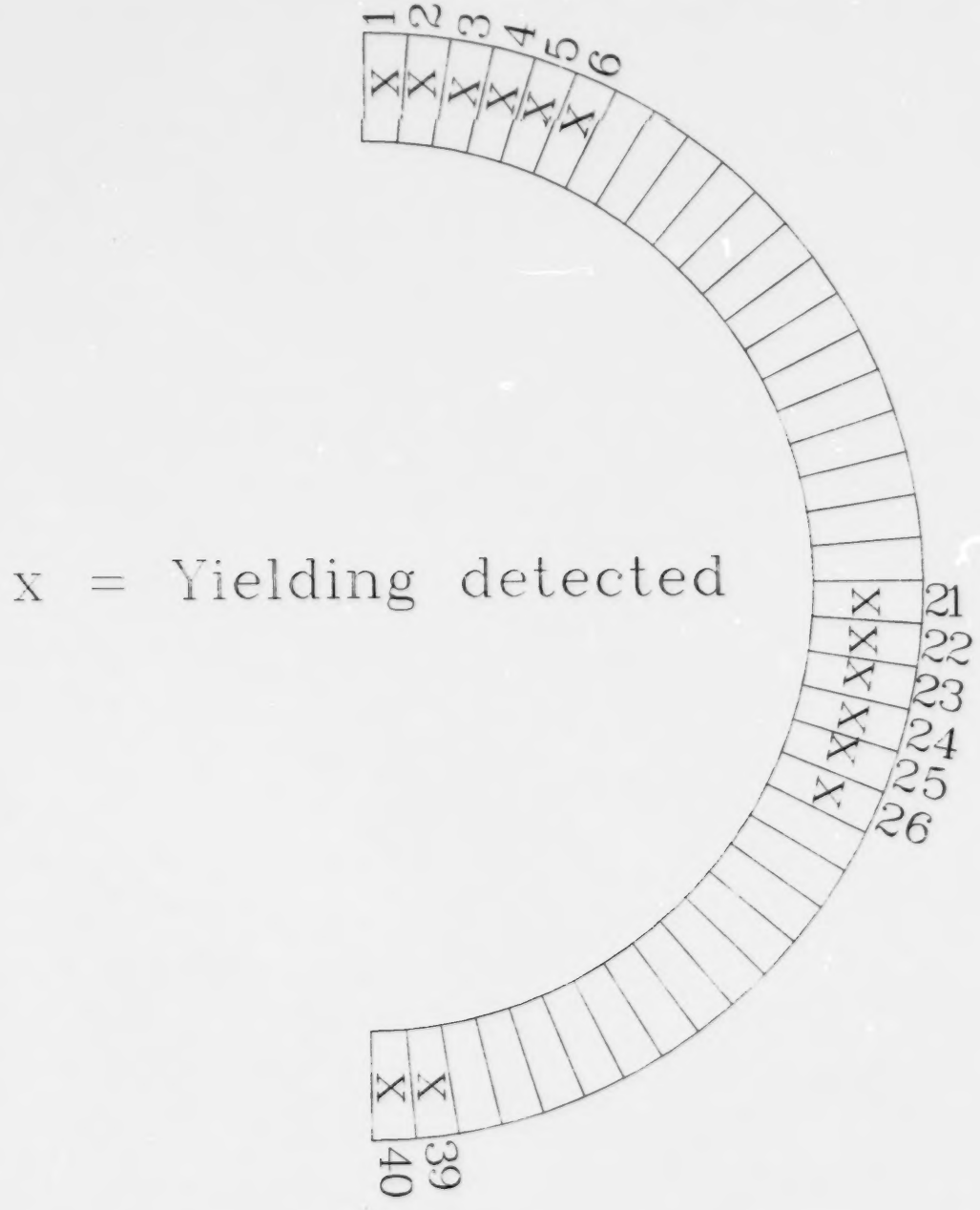


Fig 1.12 : Yielding of elements prior to support failure (example 2)

```
EXAMPLE 3:  D-TYPE SUPPORT UNDER CROWN CONC. LOAD
  1   3   25   24    2   0   1
  4000 3333 90
  1   102   10.3   81.4   9.5
  1
  0
  1   0.0   -1.0   0.0
  200   0   .268   .430
```

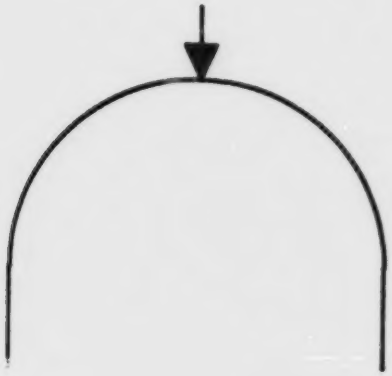


Fig. 1.13 : Datafile of example 3

```
**************************          PROGRAM  S4          ****************
***********   NONLINEAR ANALYSIS OF STEEL SET SUPPOT SYSTEMS    ****
                                BY
*************            H.S. MITRI AND F.P. HASSANI            *******
*****************             MCGILL UNIVERSITY              **********
*****************           MONTREAL, QUEBEC, 1989           *********
*******************************************************************************
DSS CONTRACT NO. 63SS.23440-7-9054
*******************************************************************************



PROBLEM TITLE : EXAMPLE 3:  D-TYPE SUPPORT UNDER CROWN C
                ONC. LOAD
STRUCTURE TYPE    =ARCH
LOAD TYPE         =GENERAL LOAD
NUMBER OF SECTIONS=    1

GEOMETRY OF THE STRUCTURE

DIAMETER   = 4000.0000
HEIGHT     = 3333.0000
SPLAY ANGLE=   90.0000
**************************     NODAL POINT DATA     ******************

NODE      X-COORD  Y-COORD    DEGREES OF FREEDOM
NUMBER                        X-DIR   Y-DIR   ROTATION

  1        .0000   3333.0000   FIXED   FREE    FIXED
  2     174.3115   3325.3894   FREE    FREE    FREE
  3     347.2964   3302.6155   FREE    FREE    FREE
  4     517.6381   3264.8516   FREE    FREE    FREE
  5     684.0403   3212.3852   FREE    FREE    FREE
  6     845.2365   3145.6156   FREE    FREE    FREE
  7    1000.0000   3065.0508   FREE    FREE    FREE
  8    1147.1529   2971.3041   FREE    FREE    FREE
  9    1285.5752   2865.0889   FREE    FREE    FREE
 10    1414.2136   2747.2135   FREE    FREE    FREE
 11    1532.0889   2618.5752   FREE    FREE    FREE
 12    1638.3041   2480.1528   FREE    FREE    FREE
 13    1732.0508   2332.9999   FREE    FREE    FREE
 14    1812.6156   2178.2365   FREE    FREE    FREE
 15    1879.3853   2017.0402   FREE    FREE    FREE
 16    1931.8517   1850.6380   FREE    FREE    FREE
 17    1969.6155   1680.2963   FREE    FREE    FREE
 18    1992.3894   1507.3114   FREE    FREE    FREE
 19    2000.0000   1332.9999   FREE    FREE    FREE
 20    2000.0000   1184.8888   FREE    FREE    FREE
 21    2000.0000   1036.7777   FREE    FREE    FREE
 22    2000.0000    888.6666   FREE    FREE    FREE
```

Fig. 1.14 : Output file of example 3

23	2000.0000	666.4999	FREE	FREE	FREE
24	2000.0000	444.3332	FREE	FREE	FREE
25	2000.0000	-.0001	FIXED	FIXED	FREE

****

********** ELEMENT DATA **********

ELEMENT NUMBER	CONNECTING NODES		IT	IS	FLANGE WIDTH	THICKNESS	WEB DEPTH	THICKNES
1	1	2	2	1	102.000	10.300	81.400	9.5
2	2	3	2	1	102.000	10.300	81.400	9.5
3	3	4	2	1	102.000	10.300	81.400	9.5
4	4	5	2	1	102.000	10.300	81.400	9.5
5	5	6	2	1	102.000	10.300	81.400	9.5
6	6	7	2	1	102.000	10.300	81.400	9.5
7	7	8	2	1	102.000	10.300	81.400	9.5
8	8	9	2	1	102.000	10.300	81.400	9.5
9	9	10	2	1	102.000	10.300	81.400	9.5
10	10	11	2	1	102.000	10.300	81.400	9.5
11	11	12	2	1	102.000	10.300	81.400	9.5
12	12	13	2	1	102.000	10.300	81.400	9.5
13	13	14	2	1	102.000	10.300	81.400	9.5
14	14	15	2	1	102.000	10.300	81.400	9.5
15	15	16	2	1	102.000	10.300	81.400	9.5
16	16	17	2	1	102.000	10.300	81.400	9.5
17	17	18	2	1	102.000	10.300	81.400	9.5
18	18	19	2	1	102.000	10.300	81.400	9.5
19	19	20	2	1	102.000	10.300	81.400	9.5
20	20	21	2	1	102.000	10.300	81.400	9.5
21	21	22	2	1	102.000	10.300	81.400	9.5
22	22	23	2	1	102.000	10.300	81.400	9.5
23	23	24	2	1	102.000	10.300	81.400	9.5
24	24	25	2	1	102.000	10.300	81.400	9.5

****

********** INITIAL LOAD DATA **********

NO. OF NODES UNDER CONCENTRATED LOAD = 1

NO. OF ELEMENTS UNDER DISTRIB. LOAD = 0

NODE	FX	FY	BM
1	.00000E+00	-.10000E+01	.00000E+00

****

********** MATERIAL PROPERTIES **********

MODULUS OF ELASTICITY = 200.000 TANGENT MODULUS = .0

YIELD STRESS = .268 ULTIMATE STRESS = .4

****

********** SOLUTION FOR LOAD INCREMENT NO.1 **********

REFERENCE LOAD = 5.1906 X INITIAL LOAD

REFERENCE LOADS

NODE	FX	FY	MX
1	.00000E+00	-.51906E+01	.00000E+00

NODAL DISPLACEMENTS

NODE	X-DIR	Y-DIR	ROT
1	.00000E+00	-.38792E+01	.00000E+00
2	.27699E-02	-.38033E+01	.84415E-03
3	.29436E-01	-.35956E+01	.15309E-02
4	.97036E-01	-.32869E+01	.20663E-02
5	.21544E+00	-.29083E+01	.24576E-02
6	.38783E+00	-.24894E+01	.27131E-02
7	.61141E+00	-.20574E+01	.28423E-02
8	.87829E+00	-.16362E+01	.28554E-02
9	.11765E+01	-.12453E+01	.27637E-02
10	.14912E+01	-.89977E+00	.25792E-02
11	.18058E+01	-.60952E+00	.23147E-02
12	.21030E+01	-.37952E+00	.19833E-02
13	.23663E+01	-.20990E+00	.15991E-02
14	.25807E+01	-.96462E-01	.11762E-02
15	.27339E+01	-.31247E-01	.72913E-03
16	.28168E+01	-.33875E-02	.27268E-03
17	.28243E+01	-.45134E-04	-.17839E-03
18	.27555E+01	-.74568E-02	-.60932E-03
19	.26141E+01	-.12035E-01	-.10055E-02
20	.24425E+01	-.10698E-01	-.13063E-02
21	.22289E+01	-.93608E-02	-.15718E-02
22	.19786E+01	-.80235E-02	-.18018E-02
23	.15459E+01	-.60177E-02	-.20805E-02
24	.10601E+01	-.40118E-02	-.22796E-02
25	.00000E+00	.00000E+00	-.24388E-02

********** SOLUTION FOR LOAD INCREMENT NO.15 ********

LOAD INCREMENT = .20
SOLUTION IS DIVERGING- FAILURE IS IMMINENT

1 ********** S U M M A R Y OF R E S U L T S *****

LOAD INCR	LOAD LEVEL			NOMINAL STIFFNESS
0	.00	X	REFERENCE LOAD	.00000E+00
1	1.00	X	REFERENCE LOAD	.41188E+00
2	2.00	X	REFERENCE LOAD	.39762E+00
3	3.00	X	REFERENCE LOAD	.39271E+00
4	4.00	X	REFERENCE LOAD	.38532E+00
5	5.00	X	REFERENCE LOAD	.37772E+00
6	6.00	X	REFERENCE LOAD	.23009E+00
7	6.20	X	REFERENCE LOAD	.12389E+00
8	6.40	X	REFERENCE LOAD	.12299E+00
9	6.60	X	REFERENCE LOAD	.12172E+00
10	6.80	X	REFERENCE LOAD	.12047E+00
11	7.00	X	REFERENCE LOAD	.11924E+00
12	7.20	X	REFERENCE LOAD	.11604E+00
13	7.40	X	REFERENCE LOAD	.11054E+00
14	7.60	X	REFERENCE LOAD	.56537E-01
15	.00	X	REFERENCE LOAD	.00000E+00

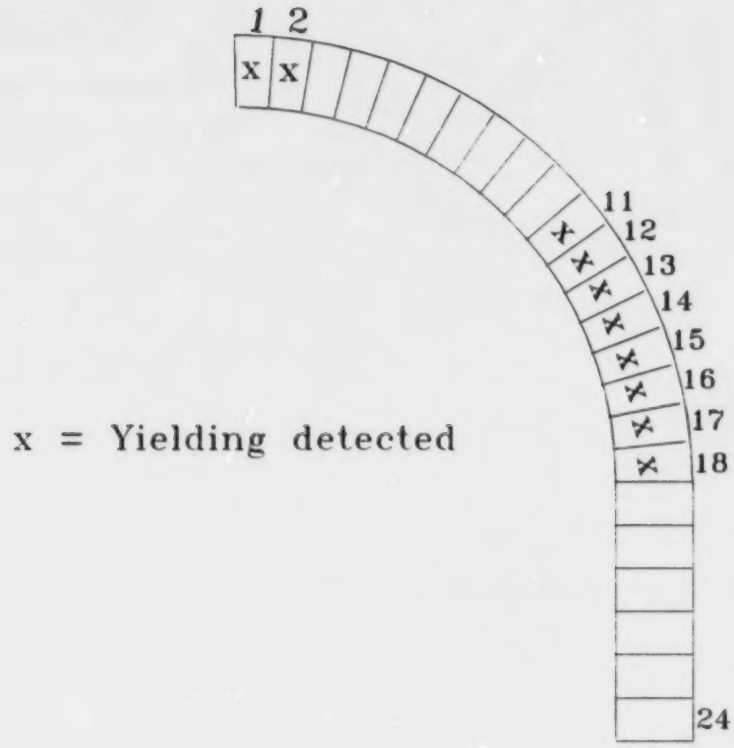


Fig. 1.15 : Yielding of elements prior to failure (example 3)

```
EXAMPLE 4:  A-TYPE SUPPORT UNDER UNIFORM PRESSURE
  1  3  25  24   3  3  1
  4000 3333 75
  1  102  10.3  81.4  9.5
  0
  50
  200  0  .268  .430
```

Fig. 1.16 : Datafile of example 4

```
************************          PROGRAM  S4          ****************
***********   NONLINEAR ANALYSIS OF STEEL SET SUPPOT SYSTEMS    ****
                                    BY
*************            H.S. MITRI AND F.P. HASSANI           *******
*****************             MCGILL UNIVERSITY              **********
*****************           MONTREAL, QUEBEC, 1989           *********
********************************************************************************
DSS CONTRACT NO. 63SS.23440-7-9054
********************************************************************************



PROBLEM TITLE : EXAMPLE 4:  A-TYPE SUPPORT UNDER UNIFORM
                PRESSURE
STRUCTURE TYPE    =SPLAY ARCH
LOAD TYPE         =PRESSURE  LOAD
NUMBER OF SECTIONS=    1

GEOMETRY OF THE STRUCTURE

DIAMETER   = 4000.0000
HEIGHT     = 3333.0000
SPLAY ANGLE=   75.0000
************************     NODAL POINT DATA     *****************
```

NODE NUMBER	X-COORD	Y-COORD	DEGREES OF FREEDOM X-DIR	Y-DIR	ROTATION
1	.0000	3333.0000	FIXED	FREE	FIXED
2	153.8475	3327.0740	FREE	FREE	FREE
3	306.7833	3309.3309	FREE	FREE	FREE
4	457.9011	3279.8761	FREE	FREE	FREE
5	606.3054	3238.8840	FREE	FREE	FREE
6	751.1166	3186.5975	FREE	FREE	FREE
7	891.4767	3123.3266	FREE	FREE	FREE
8	1026.5539	3049.4461	FREE	FREE	FREE
9	1155.5477	2965.3938	FREE	FREE	FREE
10	1277.6936	2871.6679	FREE	FREE	FREE
11	1392.2679	2768.8238	FREE	FREE	FREE
12	1498.5916	2657.4710	FREE	FREE	FREE
13	1596.0345	2538.2692	FREE	FREE	FREE
14	1684.0192	2411.9250	FREE	FREE	FREE
15	1762.0244	2279.1871	FREE	FREE	FREE
16	1829.5878	2140.8420	FREE	FREE	FREE
17	1886.3089	1997.7095	FREE	FREE	FREE
18	1931.8517	1850.6380	FREE	FREE	FREE
19	1986.9491	1645.0116	FREE	FREE	FREE
20	2070.5523	1333.0000	FREE	FREE	FREE
21	2125.6498	1127.3736	FREE	FREE	FREE
22	2208.2959	818.9339	FREE	FREE	FREE

Fig. 1.17 : Output file of example 4

23	2290.9421	510.4942	FREE	FREE	FREE
24	2373.5882	202.0545	FREE	FREE	FREE
25	2456.2344	-106.3851	FIXED	FIXED	FREE

****

********** ELEMENT DATA **********

ELEMENT NUMBER	CONNECTING NODES		IT	IS	FLANGE WIDTH	FLANGE THICKNESS	WEB DEPTH	WEB THICKNES
1	1	2	2	1	102.000	10.300	81.400	9.5
2	2	3	2	1	102.000	10.300	81.400	9.5
3	3	4	2	1	102.000	10.300	81.400	9.5
4	4	5	2	1	102.000	10.300	81.400	9.5
5	5	6	2	1	102.000	10.300	81.400	9.5
6	6	7	2	1	102.000	10.300	81.400	9.5
7	7	8	2	1	102.000	10.300	81.400	9.5
8	8	9	2	1	102.000	10.300	81.400	9.5
9	9	10	2	1	102.000	10.300	81.400	9.5
10	10	11	2	1	102.000	10.300	81.400	9.5
11	11	12	2	1	102.000	10.300	81.400	9.5
12	12	13	2	1	102.000	10.300	81.400	9.5
13	13	14	2	1	102.000	10.300	81.400	9.5
14	14	15	2	1	102.000	10.300	81.400	9.5
15	15	16	2	1	102.000	10.300	81.400	9.5
16	16	17	2	1	102.000	10.300	81.400	9.5
17	17	18	2	1	102.000	10.300	81.400	9.5
18	18	19	2	1	102.000	10.300	81.400	9.5
19	19	20	2	1	102.000	10.300	81.400	9.5
20	20	21	2	1	102.000	10.300	81.400	9.5
21	21	22	2	1	102.000	10.300	81.400	9.5
22	22	23	2	1	102.000	10.300	81.400	9.5
23	23	24	2	1	102.000	10.300	81.400	9.5
24	24	25	2	1	102.000	10.300	81.400	9.5

****

********** INITIAL LOAD DATA **********

NO. OF NODES UNDER CONCENTRATED LOAD = 0

% LOADED OF PROJECTED CROWN LENGTH = 50

ELEMENT NUMBER	DISTRIBUTED LOADS X-DIR	Y-DIR
1	-.0385	-.9993
2	-.1152	-.9933
3	-.1913	-.9815
4	-.2662	-.9639
5	-.3396	-.9406

6	-.4110	-.9117
7	-.4799	-.8773
8	-.5459	-.8378
9	-.6088	-.7934

****

********** MATERIAL PROPERTIES **********

MODULUS OF ELASTICITY = 200.000 TANGENT MODULUS = .0

YIELD STRESS = .268 ULTIMATE STRESS = .4

****

********** SOLUTION FOR LOAD INCREMENT NO.1 **********

REFERENCE LOAD = .0110 X INITIAL LOAD

NODAL DISPLACEMENTS

NODE	X-DIR	Y-DIR	ROT
1	.00000E+00	-.43682E+01	.00000E+00
2	-.64632E-03	-.43103E+01	.74868E-03
3	.16270E-01	-.41395E+01	.14764E-02
4	.67117E-01	-.38633E+01	.21624E-02
5	.16592E+00	-.34944E+01	.27861E-02
6	.32328E+00	-.30496E+01	.33272E-02
7	.54541E+00	-.25492E+01	.37661E-02
8	.83335E+00	-.20160E+01	.40837E-02
9	.11823E+01	-.14744E+01	.42615E-02
10	.15812E+01	-.94878E+00	.42821E-02
11	.20127E+01	-.46258E+00	.41357E-02
12	.24555E+01	-.34617E-01	.38407E-02
13	.28871E+01	.32319E+00	.34237E-02
14	.32859E+01	.60573E+00	.29116E-02
15	.36325E+01	.81404E+00	.23320E-02
16	.39108E+01	.95446E+00	.17131E-02
17	.41094E+01	.10375E+01	.10829E-02
18	.42220E+01	.10766E+01	.46992E-03
19	.42353E+01	.10859E+01	-.31264E-03
20	.39709E+01	.10238E+01	-.13343E-02
21	.36357E+01	.93969E+00	-.18984E-02
22	.29375E+01	.76125E+00	-.25818E-02
23	.20587E+01	.53440E+00	-.30700E-02
24	.10595E+01	.27527E+00	-.33629E-02
25	.00000E+00	.00000E+00	-.34605E-02

********** SOLUTION FOR LOAD INCREMENT NO. 7 ********

LOAD INCREMENT = .60
SOLUTION IS DIVERGING- FAILURE IS IMMINENT

1 ********** S U M M A R Y OF R E S U L T S *****

LOAD INCR	LOAD LEVEL			NOMINAL STIFFNESS
0	.00	X	REFERENCE LOAD	.00000E+00
1	1.00	X	REFERENCE LOAD	.29805E+00
2	2.00	X	REFERENCE LOAD	.26762E+00
3	2.80	X	REFERENCE LOAD	.25934E+00
4	3.60	X	REFERENCE LOAD	.24736E+00
5	4.40	X	REFERENCE LOAD	.23546E+00
6	5.00	X	REFERENCE LOAD	.21662E+00
7	.00	X	REFERENCE LOAD	.00000E+00

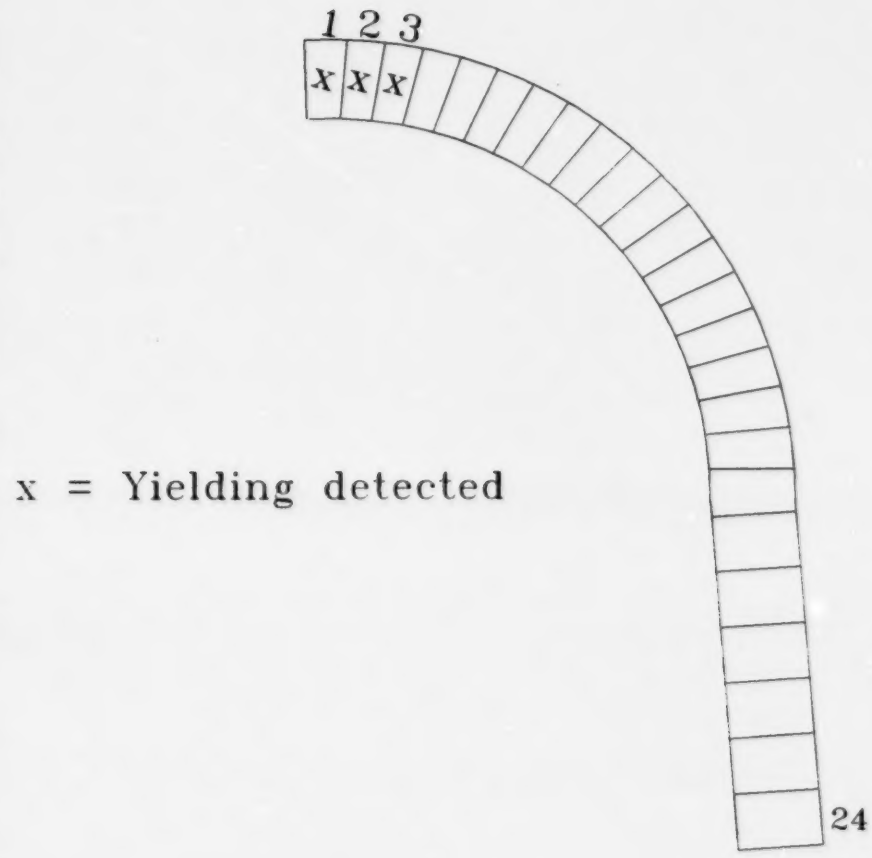


Fig. 1.18 : Yielding of elements prior to failure (example 4)

PART 2

VARIATION OF PARAMETER STUDY

2.1 LOAD DISTRIBUTION

In the following, the effect of load distribution is examined by comparing the support performance under three distinct loading patterns, namely concentrated, uniformly distributed and sinusoidal. The data used for the simulation of the models conforms with the specifications of British Standards Institute for H-section steel arches [4]. Grade A steel having a tensile strength of 430 MPa has been selected. For modelling purposes, however, a yield stress value should be defined A ratio of 1.6 of tensile strength to yield stress has been assumed which gives a yield stress of 268 MPa. Also Young's modulus of elasticity is taken as 200 GPa. With these values, the slope of the second portion of the material model is found to be 0.815 GPa. Six standard H-sections have been selected from Reference (4); their dimensional properties are listed in Table 2.1.

A total of nine models have been simulated to investigate the effect of load distribution. Data of these models is presented in Table 2.2. Each model is designated by a code consisting of letters and digits defining, respectively, support type (one or two letters), diameter in meters (one digit), leg-to-overall height ratio (one digit), loading function (one letter) and splay leg angle in degrees (2 digits). For example, model A44S-10 (Table 2.2) represents a splay-legged support, which has a diameter of 4 m and a leg-to-overall height ratio of 0.4; the loading is sinusoidal and $\phi = 10$. It is evident from the results in Fig. 2.1 that the load bearing capacity is significantly influenced by the type of loading imposed. The traditional assumption of concentrated load appears to give very conservative strength compared to other load cases. On the other hand, the highest strength and stiffness performance is predicted when a uniform loading is selected. The load-deformation curves representing the sinusoidal function are found to fall consistently between the other two curves. Ultimate strength P_u and percent deformation at failure are recorded in Table 2.2 for all cases. The results from this

parametric study suggest that the uniform loading pattern gives an overly optimistic response; (e.g. 445 KN for model A44U-10 vs 222 KN for model A44S-10 which is subjected to sinusoidal load pattern).

2.2 SECTION SIZE

Owing to the large number of parameters involoved, only one parameter will be varied at a time while holding all others constant. The effect of section size is now to be examined. Using, for example a semicircular support model such as SC40S-0 (Table 2.2 and varying the cross-section from H1 to H6, it is possible to investigate the change in ultimate strength of the support. The results are shown in Fig. 2.2 for semicircular support diameters ranging from 2 to 8 m. It is clear that there is definite improvmeent in perfomance as heavier sections are used. Typically, H6 model is 5.74 times stronger than H1 when D = 5 m. In practice, such a comparison may serve as a basis for setting alternative designs by varying the spacing between supports (thereby altering the load per arch) and the selected sections accordingly. Similar trend has been predicted by the numerical model for other support types when the section size is increased.

2.3 DIAMETER

The effect of diameter change on the support behaviour can be seen from Fig.2.2. In addition, diameters of 3 and 5 m of semicircular supports are compared with SC40S-0 (D=4 m), which are subjected to sinusoidal load as well. The comparison is presented in Fig. 2.3 and it confirms that more ductility, however less strength, is exhibited by supports of larger diameters.

2.4 LEG-TO-OVERALL HEIGHT RATIO

Plots of 3 load-deformation curves of D-type supports having λ=0.2, 0.4 and 0.6 and subjected to sinusoidal load distribution are shown in Fig. 2.4. The results indicate that D-type support models with lower leg-to overall height ratio offer higher resistance.

2.5 SPLAY LEG ANGLE

Finally, the effect of splay leg angle is demonstrated in Fig. 2.5 It is found that splaying the legs of a D-type support model (thus converting it to type A), causes significant gains both in strength and stiffness. It may be noticed that straight-line-like P-curves of Fig. 2.5 are indicative of purely elastic or inelastic buckling failure mode as was discussed earlier in Part 1.

2.6 DISCUSSION

In summary, it can be concluded that all parameters selected (load distribution, section size,diameter, leg-to-overall height ratio and splay leg angle) appear to have significant effects on the support response. While the figures presenting the results are almost self explanatory; it may be noted that λ and ϕ form an interactive pair, for while increasing λ causes deterioration in performance, splaying the legs ($\phi > 0$) counteracts this deficiency.

REFERENCES:

1. K.J. Bathe, Finite element procedures in engineering analysis, Prentice-Hall, Englewood Cliffs, N.J. (1982).

2. H.S. Mitri, FELIBS: a finite element library of subroutines, McGill University, Structural Engineering Series No. 85-4 (1985).

3. F.P. Hassani and H.S. Mitri, A microcomputer finite element software for the design of steel support systems with special reference to the Donkin-Morien project. Phase I Report submitted to Dept. EMR, Canmet, CRL Division -Sydney, N.S. (1988).

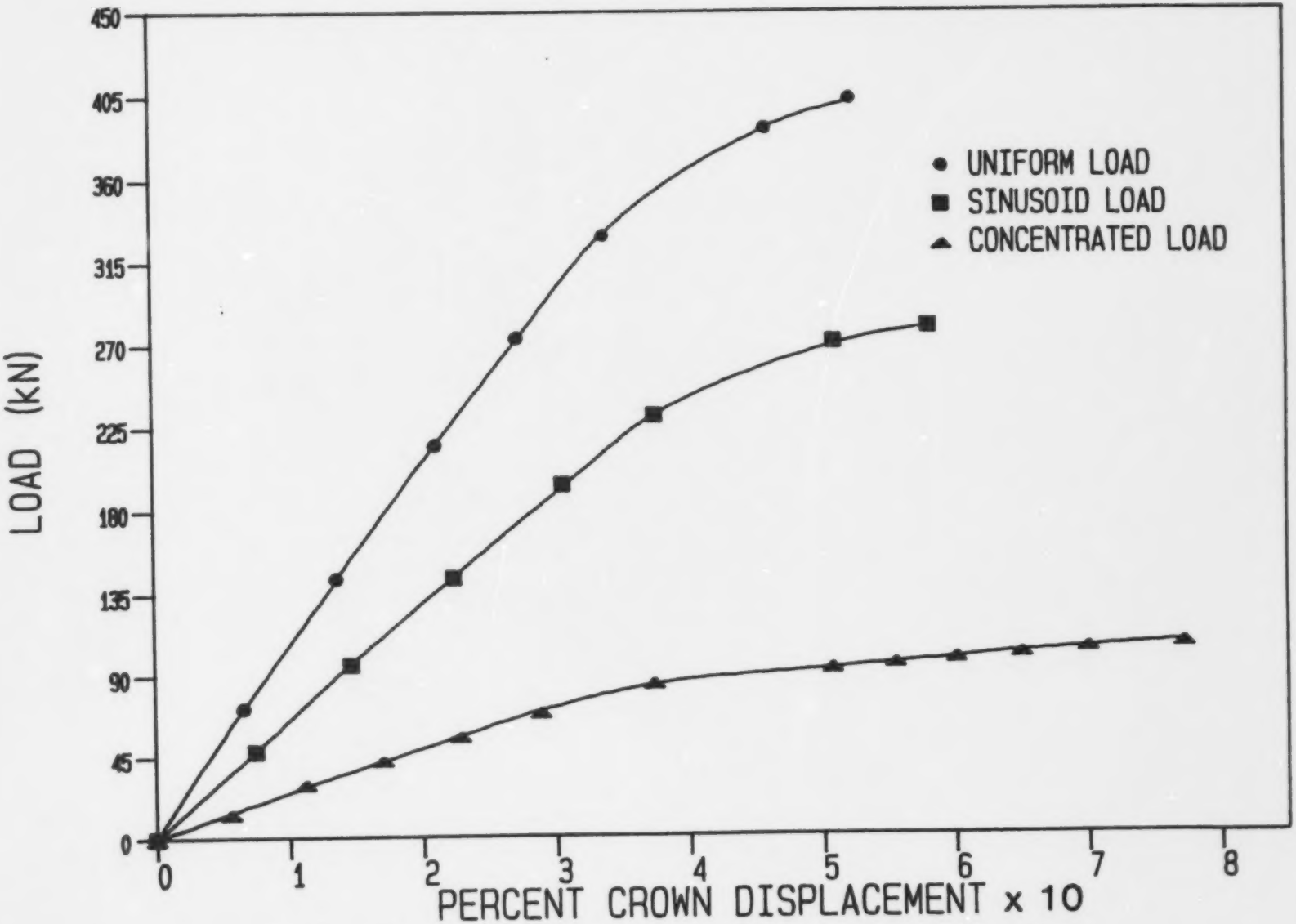


Fig. 2.1(a) : Effect of loading condition on load bearing capacity of steel support : Semicircular support

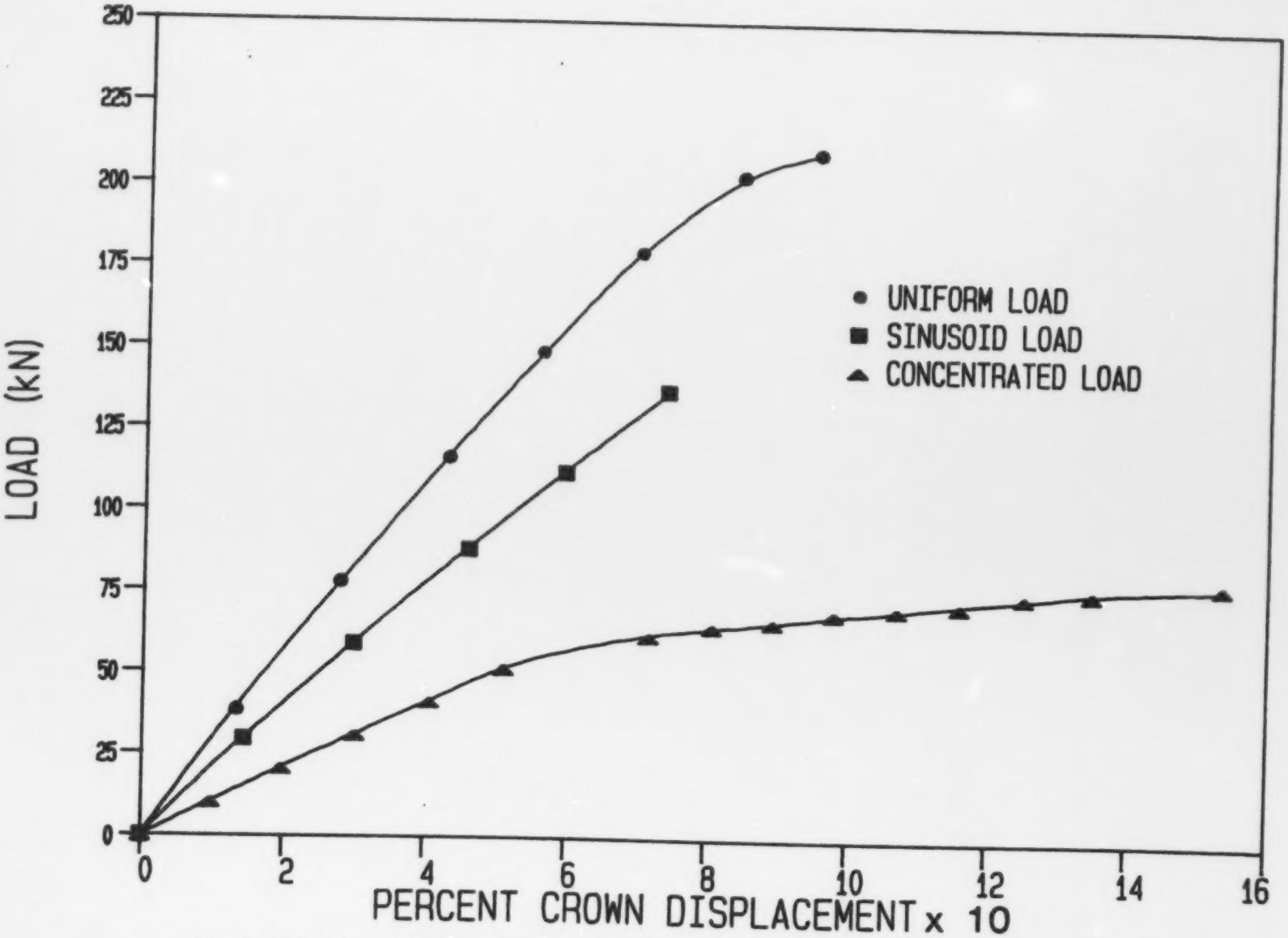


Fig. 2.1(b) : Effect of loading condition on load bearing capacity of steel support : Arch with straight legs

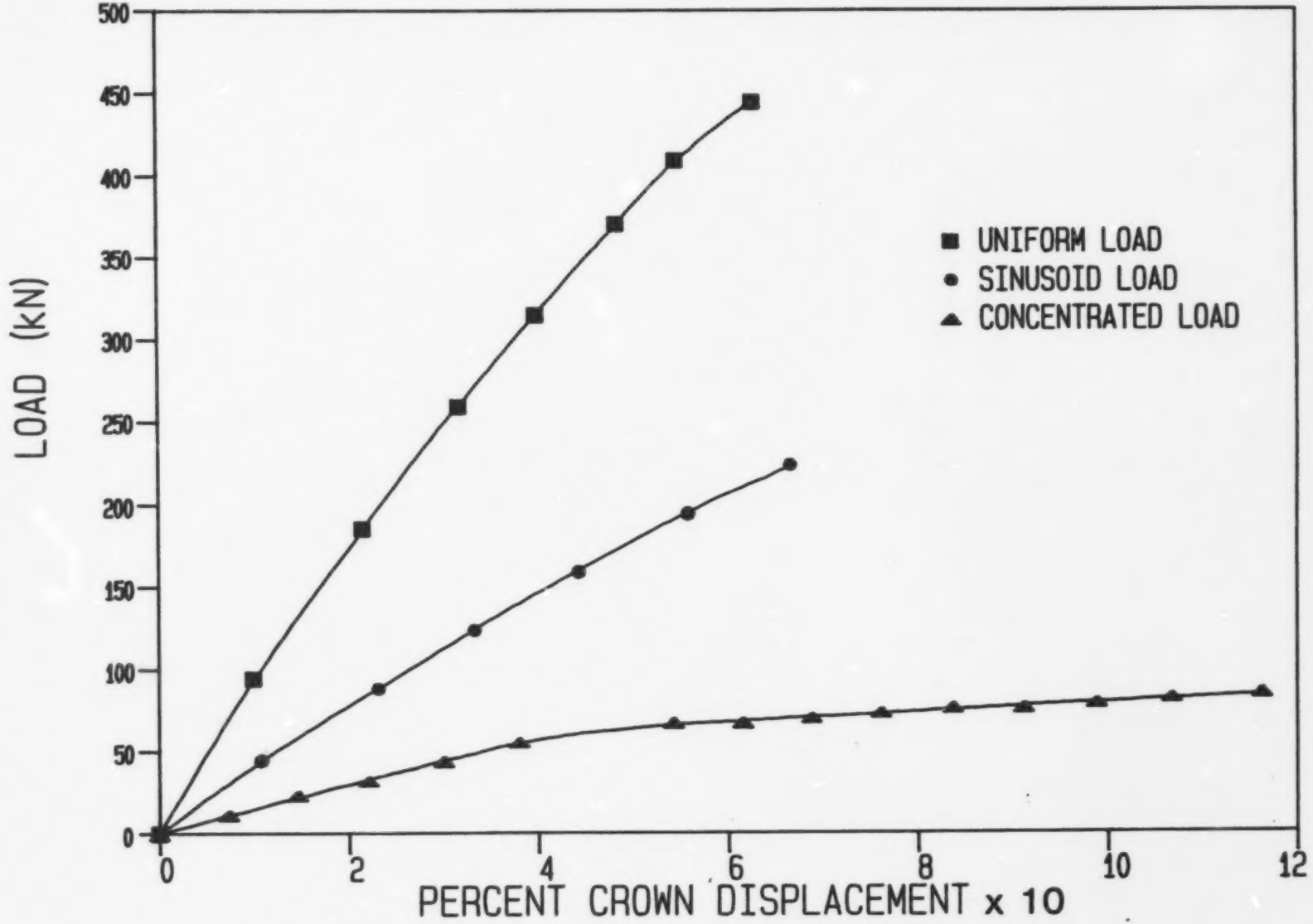


Fig 2.1(c) : Effect of loading condition on load bearing capacity of steel support : Splay legged support

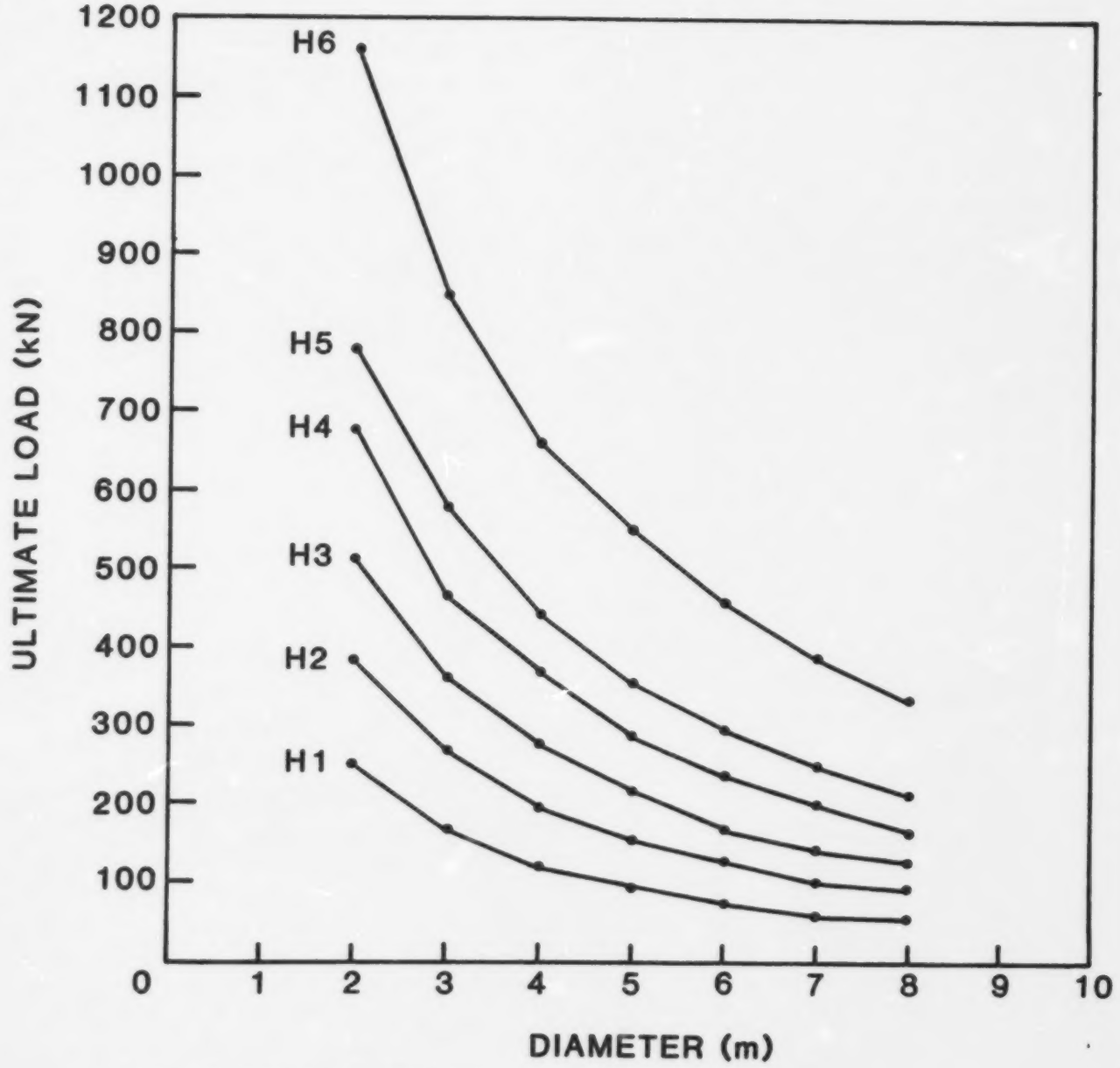


Fig. 2.2 : Effect of section size

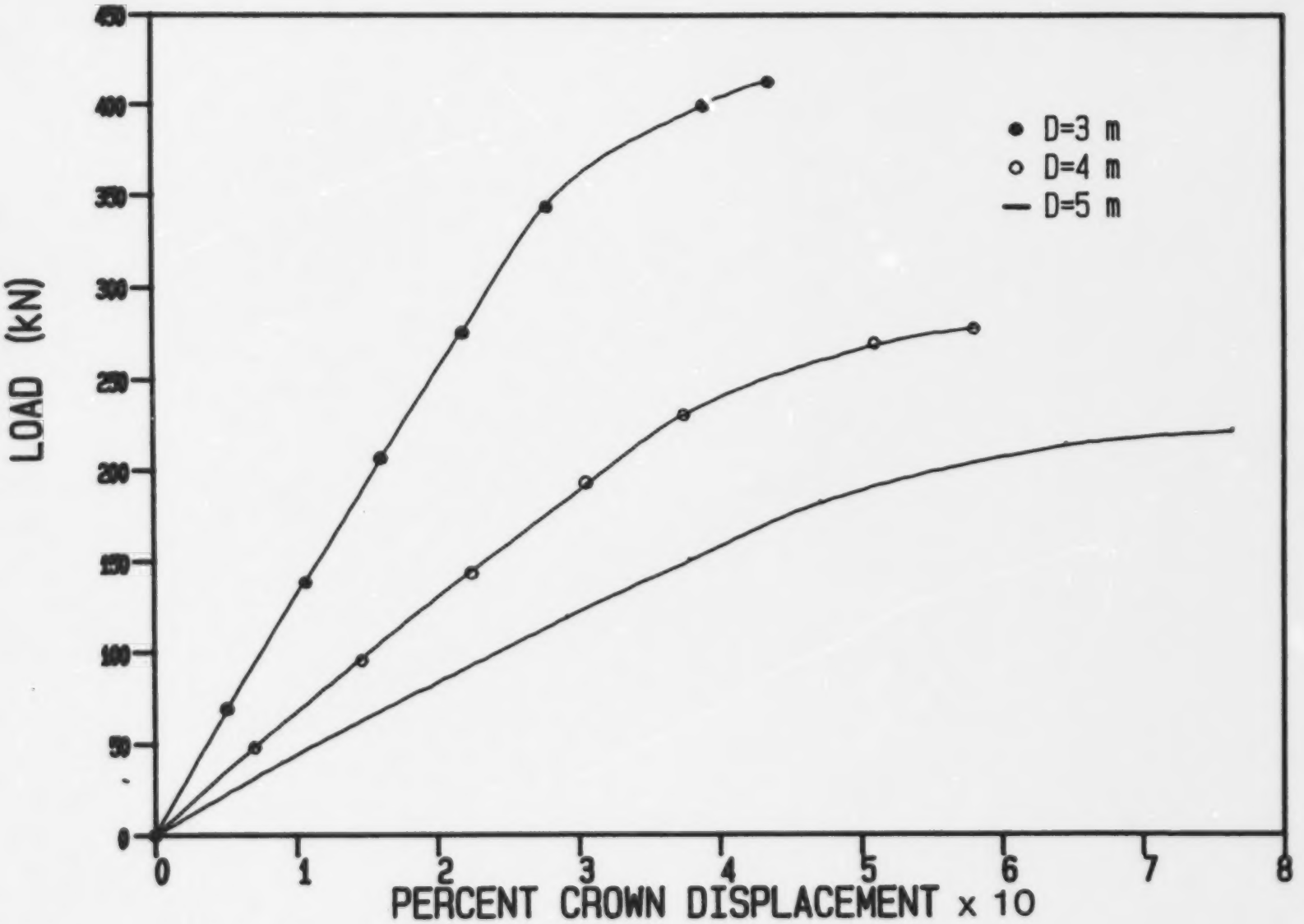


Fig. 2.3 : Effect of diameter

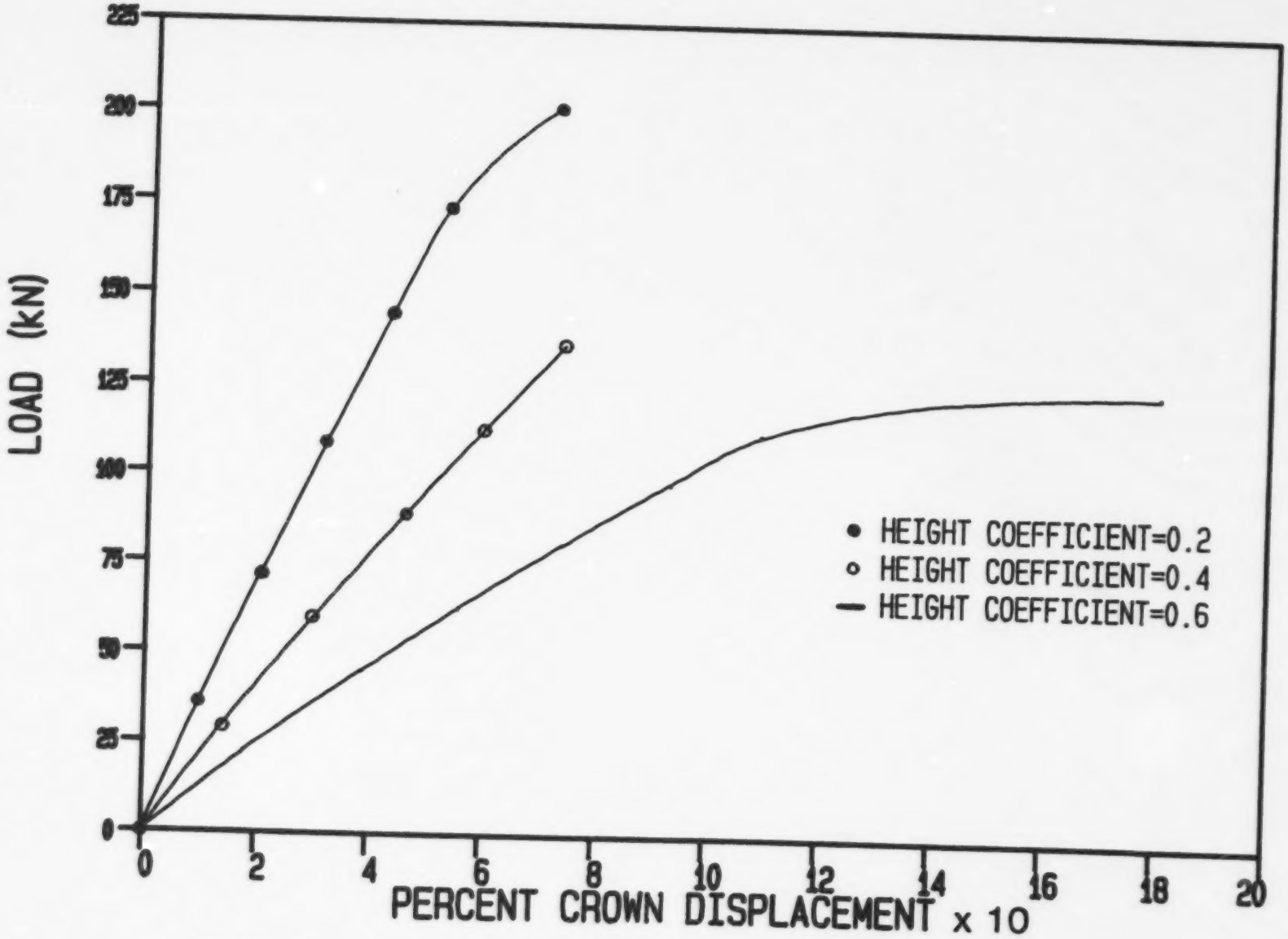


Fig. 2.4 : Effect of leg-to-overall height ratio

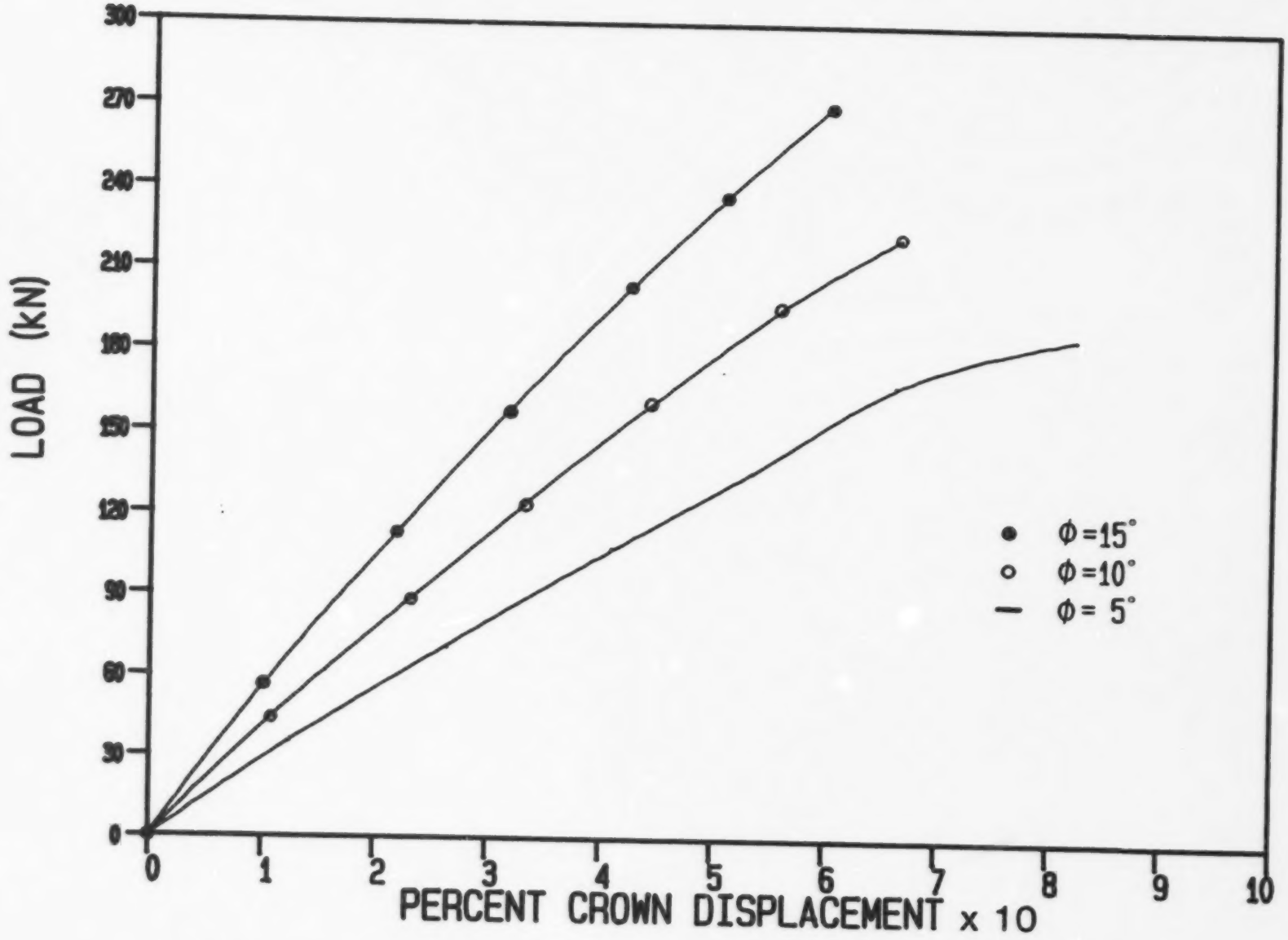


Fig. 2.5 : Effect of splay leg angle

Table 2.1: Geometric Properties of H-Sections used as Steel Supports

Section	Flange b x t (mm)	Web a x w (mm)
H1	76 x 8.4	76 x 8.9
H2	89 x 9.9	89 x 9.5
H3	102 x 10.3	102 x 9.5
H4	114 x 10.7	114 x 9.5
H5	114 x 11.5	127 x 10.2
H6	127 x 13.2	152 x 10.4

Table 2.2: Effect of Load Distribution on the Behaviour of Different Supports

Model Designation	Support type	D (m)	λ	Load Distribution	P_u (kN)	% Deformation
SC40U-0	SC	4	0	uniform	401	0.524
SC40S-0	SC	4	0	sinusoid	278	0.581
SC40C-0	SC	4	0	concentrated	106	0.773
D44U-0	D	4	0.4	uniform	210	0.951
D44S-0	D	4	0.4	sinusoid	136	0.738
D44C-0	D	4	0.4	concentrated	79	1.534
A44U-10	A	4	0.4	uniform	445	0.617
A44S-10	A	4	0.4	sinusoid	222	0.656
A44C-10	A	4	0.4	concentrated	84	1.147

Note: H-section used: H3 (Table 2.1)

Table 2.3: Model Data and Results of Shape Effect Analysis

Model Designation	Support type	D (m)	λ	ϕ	P_u (kN)	% Deformation
SC30S-0	SC	3	0	0	414	0.435
SC40S-0	SC	4	0	0	278	0.581
SC50S-0	SC	5	0	0	221	0.763
D42S-0	D	4	0.2	0	202	0.72
D44S-0	D	4	0.4	0	136	0.738
D46S-0	D	4	0.6	0	108	1.804
A44S-5	A	4	0.4	5	186	0.819
A44S-10	A	4	0.4	10	222	0.656
A44S-15	A	4	0.4	15	270	0.518

Note: Sinusoidal load distribution, H-section used: H3 (Table 2.1)

Table 2.4 :Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D2.2S-0-H1	2000	0.2	0	190.96	0.567
D3.2S-0-H1	3000	0.2	0	125.28	0.812
D4.2S-0-H1	4000	0.2	0	90.72	0.987
D5.2S-0-H1	5000	0.2	0	67.5	1.082
D6.2S-0-H1	6000	0.2	0	54.72	1.286
D7.2S-0-H1	7000	0.2	0	45.08	1.476
D8.2S-0-H1	8000	0.2	0	36.8	1.829
D2.2S-0-H2	2000	0.2	0	295.12	0.456
D3.2S-0-H2	3000	0.2	0	203.4	0.757
D4.2S-0-H2	4000	0.2	0	147.84	0.875
D5.2S-0-H2	5000	0.2	0	111.84	0.955
D6.2S-0-H2	6000	0.2	0	90.0	1.123
D7.2S-0-H2	7000	0.2	0	73.92	1.278
D8.2S-0-H2	8000	0.2	0	62.56	1.422
D2.2S-0-H3	2000	0.2	0	400.52	0.391
D3.2S-0-H3	3000	0.2	0	277.40	0.599

Table 2.4 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	%δ
D4.2S-0-H3	4000	0.2	0	201.6	0.715
D5.2S-0-H3	5000	0.2	0	159.30	0.888
D6.2S-0-H3	6000	0.2	0	126.0	0.927
D7.2S-0-H3	7000	0.2	0	104.16	1.058
D8.2S-0-H3	8000	0.2	0	92.16	1.282
D2.2S-0-H4	2000	0.2	0	514.35	0.347
D3.2S-0-H4	3000	0.2	0	358.2	0.517
D4.2S-0-H4	4000	0.2	0	271.44	0.693
D5.2S-0-H4	5000	0.2	0	215.6	0.877
D6.2S-0-H4	6000	0.2	0	168.48	0.887
D7.2S-0-H4	7000	0.2	0	140.0	0.993
D8.2S-0-H4	8000	0.2	0	119.04	1.091
D2.2S-0-H5	2000	0.2	0	632.32	0.355
D3.2S-0-H5	3000	0.2	0	444.54	0.510
D4.2S-0-H5	4000	0.2	0	338.4	0.701
D5.2S-0-H5	5000	0.2	0	260.4	0.725
D6.2S-0-H5	6000	0.2	0	213.84	0.847
D7.2S-0-H5	7000	0.2	0	178.36	0.953
D8.2S-0-H5	8000	0.2	0	152.0	1.0369
D2.2S-0-H6	2000	0.2	0	894.04	0.255
D3.2S-0-H6	3000	0.2	0	658.44	0.401

Table 2.4 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D4.2S-0-H6	4000	0.2	0	504.0	0.521
D5.2S-0-H6	5000	0.2	0	403.1	0.632
D6.2S-0-H6	6000	0.2	0	332.64	0.733
D7.2S-0-H6	7000	0.2	0	279.72	0.826
D8.2S-0-H6	8000	0.2	0	237.12	0.894

Table 2.5 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D2.3S-0-H1	2000	0.3	0	165.6	0.611
D3.3S-0-H1	3000	0.3	0	107.6	0.863
D4.3S-0-H1	4000	0.3	0	76.96	1.055
D5.3S-0-H1	5000	0.3	0	57.6	1.212
D6.3S-0-H1	6000	0.3	0	48.96	1.583
D7.3S-0-H1	7000	0.3	0	36.96	1.678
D8.3S-0-H1	8000	0.3	0	8.0*	0.335*
D2.3S-0-H2	2000	0.3	0	265.36	0.574
D3.3S-0-H2	3000	0.3	0	175.74	0.789
D4.3S-0-H2	4000	0.3	0	125.28	0.934
D5.3S-0-H2	5000	0.3	0	95.0	1.047
D6.3S-0-H2	6000	0.3	0	77.76	1.25
D7.3S-0-H2	7000	0.3	0	67.2	1.574
D8.3S-0-H2	8000	0.3	0	52.8	1.623
D2.3S-0-H3	2000	0.3	0	360.84	0.479
D3.3S-0-H3	3000	0.3	0	240.12	0.647
D4.3S-0-H3	4000	0.3	0	179.2	0.877

* Arch failed by buckling.

Table 2.5 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D5.3S-0-H3	5000	0.3	0	135.0	0.962
D6.3S-0-H3	6000	0.3	0	111.0	1.131
D7.3S-0-H3	7000	0.3	0	90.72	1.281
D8.3S-0-H3	8000	0.3	0	80.64	1.596
D2.3S-0-H4	2000	0.3	0	463.76	0.418
D3.3S-0-H4	3000	0.3	0	320.4	0.676
D4.3S-0-H4	4000	0.3	0	232.96	0.748
D5.3S-0-H4	5000	0.3	0	183.6	0.923
D6.3S-0-H4	6000	0.3	0	149.76	1.082
D7.3S-0-H4	7000	0.3	0	126.0	1.219
D8.4S-0-H4	8000	0.3	0	107.52	1.333
D2.3S-0-H5	2000	0.3	0	572.16	0.437
D3.3S-0-H5	3000	0.3	0	387.0	0.548
D4.3S-0-H5	4000	0.3	0	292.32	0.741
D5.3S-0-H5	5000	0.3	0	199.2	1.059
D6.3S-0-H5	6000	0.3	0	160.08	0.754
D7.3S-0-H5	7000	0.3	0	150.5	1.036
D8.3S-0-H5	8000	0.3	0	136.0	1.272
D2.3S-0-H6	2000	0.3	0	839.68	0.365
D3.3S-0-H6	3000	0.3	0	593.34	0.498
D4.3S-0-H6	4000	0.3	0	451.2	0.698

* Arch failed by buckling.

Table 2.5 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D5.3S-0-H6	5000	0.3	0	347.2	0.684
D6.3S-0-H6	6000	0.3	0	253.44	0.636
D7.3S-0-H6	7000	0.3	0	249.48	1.022
D8.3S-0-H6	8000	0.3	0	212.16	1.095

* Arch failed by buckling.

Table 2.6 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D2.4S-0-H1	2000	0.4	0	147.32	0.733
D3.4S-0-H1	3000	0.4	0	95.58	0.987
D4.4S-0-H1	4000	0.4	0	68.0	1.199
D5.4S-0-H1	5000	0.4	0	52.8	1.514
D6.4S-0-H1	6000	0.4	0	39.4	1.689
D7.4S-0-H1	7000	0.4	0	7.7*	0.349*
D8.4S-0-H1	8000	0.4	0	7.2*	0.402*
D2.4S-0-H2	2000	0.4	0	229.68	0.553
D3.4S-0-H2	3000	0.4	0	156.24	1.016
D4.4S-0-H2	4000	0.4	0	112.32	1.056
D5.4S-0-H2	5000	0.4	0	87.5	1.325
D6.4S-0-H2	6000	0.4	0	72.0	1.567
D7.4S-0-H2	7000	0.4	0	55.44	1.680
D8.4S-0-H2	8000	0.4	0	49.28	2.007
D2.4S-0-H3	2000	0.4	0	324.0	0.563
D3.4S-0-H3	3000	0.4	0	213.36	0.741
D4.4S-0-H3	4000	0.4	0	159.84	1.084

Table 2.6 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D5.4S-0-H3	5000	0.4	0	120.0	1.090
D6.4S-0-H3	6000	0.4	0	97.92	1.295
D7.4S-0-H3	7000	0.4	0	84.0	1.634
D8.4S-0-H3	8000	0.4	0	66.88	1.672
D2.4S-0-H4	2000	0.4	0	415.2	0.472
D3.4S-0-H4	3000	0.4	0	285.36	0.898
D4.4S-0-H4	4000	0.4	0	184.32	0.676
D5.4S-0-H4	5000	0.4	0	163.8	1.044
D6.4S-0-H4	6000	0.4	0	132.0	1.222
D7.4S-0-H4	7000	0.4	0	110.88	1.378
D8.4S-0-H4	8000	0.4	0	84.0	1.759
D2.4S-0-H5	2000	0.4	0	514.6	0.503
D3.4S-0-H5	3000	0.4	0	344.52	0.652
D4.4S-0-H5	4000	0.4	0	259.84	0.595
D5.4S-0-H5	5000	0.4	0	174.8	0.741
D6.4S-0-H5	6000	0.4	0	149.04	0.926
D7.4S-0-H5	7000	0.4	0	140.0	1.320
D8.4S-0-H5	8000	0.4	0	119.04	1.435

Table 2.6 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D2.4S-0-H6	2000	0.4	0	757.64	0.368
D3.4S-0-H6	3000	0.4	0	531.0	0.483
D4.4S-0-H6	4000	0.4	0	348.0	0.503
D5.4S-0-H6	5000	0.4	0	273.6	0.626
D6.4S-0-H6	6000	0.4	0	223.58	0.742
D7.4S-0-H6	7000	0.4	0	193.2	0.896
D8.4S-0-H6	8000	0.4	0	188.0	1.23

* Arch failed by buckling.

Table 2.7 : Effect of Sinusoidal Load Distribution on the Behaviour of Straight Leg Arch (D-Type)

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D2.6S-0-H1	2000	0.6	0	112.0	0.922
D3.6S-0-H1	3000	0.6	0	73.92	1.612
D4.6S-0-H1	4000	0.6	0	48.0	1.477
D5.6S-0-H1	5000	0.6	0	38.4	1.984
D6.6S-0-H1	6000	0.6	0	6.6*	0.362*
D7.6S-0-H1	7000	0.6	0	5.6*	0.423*
D8.6S-0-H1	8000	0.6	0	4.8*	0.483*
D2.6S-0-H2	2000	0.6	0	178.08	0.716
D3.6S-0-H2	3000	0.6	0	110.76	0.965
D4.6S-0-H2	4000	0.6	0	76.8	1.217
D5.6S-0-H2	5000	0.6	0	67.6	2.083
D6.6S-0-H2	6000	0.6	0	51.84	2.053
D7.6S-0-H2	7000	0.6	0	9.1*	0.361*
D8.6S-0-H2	8000	0.6	0	8.0*	0.412*
D2.6S-0-H3	2000	0.6	0	266.4	0.994
D3.6S-0-H3	3000	0.6	0	160.38	0.917
D4.6S-0-H3	4000	0.6	0	112.0	1.090
D5.6S-0-H3	5000	0.6	0	86.4	1.351

* Arch failed by buckling.

Table 2.7 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	%δ
D6.6S-0-H3	6000	0.6	0	69.0	1.604
D7.6S-0-H3	7000	0.6	0	63.0	2.555
D8.6S-0-H3	8000	0.6	0	11.2*	0.359*
D2.6S-0-H4	2000	0.6	0	349.2	0.868
D3.6S-0-H4	3000	0.6	0	218.4	0.952
D4.6S-0-H4	4000	0.6	0	153.92	1.429
D5.6S-0-H4	5000	0.6	0	112.8	1.181
D6.6S-0-H4	6000	0.6	0	102.96	1.954
D7.6S-0-H4	7000	0.6	0	80.64	1.823
D8.6S-0-H4	8000	0.6	0	72.0	2.722
D2.6S-0-H5	2000	0.6	0	411.8	0.624
D3.6S-0-H5	3000	0.6	0	276.12	0.836
D4.6S-0-H5	4000	0.6	0	165.6	0.763
D5.6S-0-H5	5000	0.6	0	142.5	1.729
D6.6S-0-H5	6000	0.6	0	115.2	1.293
D7.6S-0-H5	7000	0.6	0	105.56	2.121
D8.6S-0-H5	8000	0.6	0	92.0	2.267
D2.6S-0-H6	2000	0.6	0	543.0	0.343
D3.6S-0-H6	3000	0.6	0	408.24	0.661
D4.6S-0-H6	4000	0.6	0	309.12	0.963

* Arch failed by buckling.

Table 2.7 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	$\%\delta$
D5.6S-0-H6	5000	0.6	0	246.4	1.289
D6.6S-0-H6	6000	0.6	0	197.64	1.467
D7.6S-0-H6	7000	0.6	0	170.10	1.945
D8.6S-0-H6	8000	0.6	0	145.6	1.981

* Arch failed by buckling.

Table 2.8 : Effect of Sinusoidal Load Distribution on the Behaviour of Semi-circular Arch

MODEL DESIGNATION.	DIA (mm)	ϕ (DEG)	Pu (Kn)	% δ
SC2S-H1	2000	0	250.48	0.398
SC3S-H1	3000	0	167.04	0.567
SC4S-H1	4000	0	120.96	0.697
SC5S-H1	5000	0	96.20	0.899
SC6S-H1	6000	0	74.88	0.932
SC7S-H1	7000	0	58.52	1.006
SC8S-H1	8000	0	55.2	1.359
SC2S-H2	2000	0	384.4	0.330
SC3S-H2	3000	0	270.0	0.510
SC4S-H2	4000	0	197.12	0.617
SC5S-H2	5000	0	156.6	0.784
SC6S-H2	6000	0	127.92	0.958
SC7S-H2	7000	0	100.8	0.926
SC8S-H2	8000	0	92.16	1.194
SC2S-H3	2000	0	515.84	0.286
SC3S-H3	3000	0	365.4	0.426
SC4S-H3	4000	0	278.4	0.578

Table 2.8 continued...

MODEL DESIGNATION.	DIA (mm)	ϕ (DEG)	Pu (Kn)	% δ
SC5S-H3	5000	0	221.2	0.737
SC6S-H3	6000	0	168.0	0.664
SC7S-H3	7000	0	141.12	0.762
SC8S-H3	8000	0	126.72	0.932
SC2S-H4	2000	0	677.12	0.407
SC3S-H4	3000	0	468.0	0.373
SC4S-H4	4000	0	372.0	0.577
SC5S-H4	5000	0	288.4	0.614
SC6S-H4	6000	0	236.52	0.722
SC7S-H4	7000	0	200.2	0.820
SC8S-H4	8000	0	161.28	0.786
SC2S-H5	2000	0	777.48	0.227
SC3S-H5	3000	0	578.46	0.358
SC4S-H5	4000	0	446.4	0.473
SC5S-H5	5000	0	356.7	0.586
SC6S-H5	6000	0	295.68	0.691
SC7S-H5	7000	0	249.48	0.789
SC8S-H5	8000	0	212.16	0.860
SC2S-H6	2000	0	1158.4	0.292
SC3S-H6	3000	0	846.3	0.291

Table 2.8 continued...

MODEL DESIGNATION.	DIA (mm)	ϕ (DEG)	Pu (Kn)	% δ
SC4S-H6	4000	0	660.0	0.373
SC5S-H6	5000	0	552.0	0.515
SC6S-H6	6000	0	459.36	0.596
SC7S-H6	7000	0	388.08	0.668
SC8S-H6	8000	0	332.64	0.727

Table 2.9 : Effect of Sinusoidal Load Distribution on the Behaviour of Splay Leg Arch (A-Type)

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A2.2S-5-H1	2000	0.2	5	208.58	0.576
A3.2S-5-H1	3000	0.2	5	132.68	0.701
A4.2S-5-H1	4000	0.2	5	92.31	0.788
A5.2S-5-H1	5000	0.2	5	71.39	0.995
A6.2S-5-H1	6000	0.2	5	59.45	1.196
A7.2S-5-H1	7000	0.2	5	47.38	1.383
A8.2S-5-H1	8000	0.2	5	41.35	1.553
A2.2S-5-H2	2000	0.2	5	323.05	0.453
A3.2S-5-H2	3000	0.2	5	215.95	0.629
A4.2S-5-H2	4000	0.2	5	155.08	0.763
A5.2S-5-H2	5000	0.2	5	117.95	0.860
A6.2S-5-H2	6000	0.2	5	94.53	1.027
A7.2S-5-H2	7000	0.2	5	79.26	1.188
A8.2S-5-H2	8000	0.2	5	68.59	1.337
A2.2S-5-H3	2000	0.2	5	437.52	0.384
A3.2S-5-H3	3000	0.2	5	304.63	0.611
A4.2S-5-H3	4000	0.2	5	222.86	0.709

Table 2.9 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A5.2S-5-H3	5000	0.2	5	174.47	0.901
A6.2S-5-H3	6000	0.2	5	144.01	1.081
A7.2S-5-H3	7000	0.2	5	113.73	1.057
A8.2S-5-H3	8000	0.2	5	98.138	1.183
A2.2S-5-H4	2000	0.2	5	558.35	0.338
A3.2S-5-H4	3000	0.2	5	391.41	0.520
A4.2S-5-H4	4000	0.2	5	297.45	0.718
A5.2S-5-H4	5000	0.2	5	227.09	0.754
A6.2S-5-H4	6000	0.2	5	181.54	0.787
A7.2S-5-H4	7000	0.2	5	154.36	1.004
A8.2S-5-H4	8000	0.2	5	133.91	1.102
A2.2S-5-H5	2000	0.2	5	686.64	0.379
A3.2S-5-H5	3000	0.2	5	486.49	0.512
A4.2S-5-H5	4000	0.2	5	356.94	0.548
A5.2S-5-H5	5000	0.2	5	284.32	0.721
A6.2S-5-H5	6000	0.2	5	232.63	0.850
A7.2S-5-H5	7000	0.2	5	197.88	0.963
A8.2S-5-H5	8000	0.2	5	161.48	0.939
A2.2S-5-H6	2000	0.2	5	1000.42	0.324
A3.2S-5-H6	3000	0.2	5	717.33	0.398

Table 2.9 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A4.2S-5-H6	4000	0.2	5	551.41	0.523
A5.2S-5-H6	5000	0.2	5	443.20	0.640
A6.2S-5-H6	6000	0.2	5	365.31	0.733
A7.2S-5-H6	7000	0.2	5	306.29	0.818
A8.2S-5-H6	8000	0.2	5	250.27	0.797

Table 2.10 : Effect of Sinusoidal Load Distribution on the Behaviour of Splay Leg (A-Type)

MODEL DESIGNATION	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A2.2S-10-H1	2000	0.2	10	231.39	0.523
A3.2S-10-H1	3000	0.2	10	153.08	0.783
A4.2S-10-H1	4000	0.2	10	110.19	0.920
A5.2S-10-H1	5000	0.2	10	83.91	1.029
A6.2S-10-H1	6000	0.2	10	64.33	1.144
A7.2S-10-H1	7000	0.2	10	55.476	1.444
A8.2S-10-H1	8000	0.2	10	46.28	1.626
A2.2A-10-H2	2000	0.2	10	369.17	0.495
A3.2S-10-H2	3000	0.2	10	247.03	0.727
A4.2S-10-H2	4000	0.2	10	180.79	0.817
A5.2S-10-H2	5000	0.2	10	132.23	0.811
A6.2S-10-H2	6000	0.2	10	105.27	0.978
A7.2S-10-H2	7000	0.2	10	88.11	1.137
A8.2S-10-H2	8000	0.2	10	78.32	1.388
A2.2S-10-H3	2000	0.2	10	496.61	0.409
A3.2S-10-H3	3000	0.2	10	337.37	0.555

Table 2.10 continued...

MODEL DESIGNATION	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A4.2S-10-H3	4000	0.2	10	247.16	0.648
A5.2S-10-H3	5000	0.2	10	195.58	0.824
A6.2S-10-H3	6000	0.2	10	152.57	0.867
A7.2S-10-H3	7000	0.2	10	126.23	1.004
A8.2S-10-H3	8000	0.2	10	108.15	1.130
A2.2S-10-H4	2000	0.2	10	633.25	0.371
A3.2S-10-H4	3000	0.2	10	433.23	0.469
A4.2S-10-H4	4000	0.2	10	329.89	0.647
A5.2S-10-H4	5000	0.2	10	263.18	0.850
A6.2S-10-H4	6000	0.2	10	206.60	0.818
A7.2S-10-H4	7000	0.2	10	174.44	0.934
A8.2S-10-H4	8000	0.2	10	148.16	1.033
A2.2S-10-H5	2000	0.2	10	752.80	0.300
A3.2S-10-H5	3000	0.2	10	535.90	0.462
A4.2S-10-H5	4000	0.2	10	410.49	0.525
A5.2S-10-H5	5000	0.2	10	317.53	0.659
A6.2S-10-H5	6000	0.2	10	261.15	0.782
A7.2S-10-H5	7000	0.2	10	210.04	0.791
A8.2S-10-H5	8000	0.2	10	187.15	0.977

Table 2.10 continued...

MODEL DESIGNATION	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A2.2S-10-H6	2000	0.2	10	1090.45	0.246
A3.2S-10-H6	3000	0.2	10	778.59	0.356
A4.2S-10-H6	4000	0.2	10	609.60	0.474
A5.2S-10-H6	5000	0.2	10	489.50	0.578
A6.2S-10-H6	6000	0.2	10	405.07	0.668
A7.2S-10-H6	7000	0.2	10	326.33	0.670
A8.2S-10-H6	8000	0.2	10	292.42	0.824

Table 2.11 : Effect of Sinusoidal Load Distribution on the Behaviour of Splay Leg Arch (A-Type)

MODEL DESIGNATION	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A2.2S-15-H1	2000	0.2	15	279.09	0.524
A3.2S-15-H1	3000	0.2	15	166.99	0.504
A4.2S-15-H1	4000	0.2	15	124.86	0.705
A5.2S-15-H1	5000	0.2	15	94.57	0.850
A6.2S-15-H1	6000	0.2	15	78.57	1.121
A7.2S-15-H1	7000	0.2	15	64.81	1.319
A8.2S-15-H1	8000	0.2	15	56.44	1.497
A2.2S-15-H2	2000	0.2	15	428.56	0.398
A3.2S-15-H2	3000	0.2	15	290.13	0.571
A4.2S-15-H2	4000	0.2	15	205.02	0.605
A5.2S-15-H2	5000	0.2	15	161.37	0.777
A6.2S-15-H2	6000	0.2	15	125.13	0.878
A7.2S-15-H2	7000	0.2	15	108.64	1.112
A8.2S-15-H2	8000	0.2	15	92.59	1.265
A2.2S-15-H3	2000	0.2	15	575.38	0.329
A3.2S-15-H3	3000	0.2	15	408.52	0.561

Table 2.11 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A4.2S-15-H3	4000	0.2	15	299.99	0.658
A5.2S-15-H3	5000	0.2	15	222.22	0.633
A6.2S-15-H3	6000	0.2	15	179.49	0.769
A7.2S-15-H3	7000	0.2	15	149.38	0.898
A8.2S-15-H3	8000	0.2	15	131.92	1.108
A2.2S-15-H4	2000	0.2	15	728.82	0.288
A3.2S-15-H4	3000	0.2	15	523.59	0.460
A4.2S-15-H4	4000	0.2	15	388.08	0.525
A5.2S-15-H4	5000	0.2	15	311.81	0.681
A6.2S-15-H4	6000	0.2	15	254.62	0.828
A7.2S-15-H4	7000	0.2	15	214.81	0.943
A8.2S-15-H4	8000	0.2	15	182.53	1.050
A2.2S-15-H5	2000	0.2	15	892.53	0.322
A3.2S-15-H5	3000	0.2	15	644.82	0.455
A4.2S-15-H5	4000	0.2	15	481.47	0.524
A5.2S-15-H5	5000	0.2	15	386.89	0.686
A6.2S-15-H5	6000	0.2	15	295.23	0.602
A7.2S-15-H5	7000	0.2	15	259.25	0.766
A8.2S-15-H5	8000	0.2	15	209.52	0.794

Table 2.11 continued...

MODEL DESIGNATION.	DIA (mm)	λ	ϕ (DEG)	Pu (Kn)	% δ
A2.2S-15-H6	2000	0.2	15	1283.43	0.275
A3.2S-15-H6	3000	0.2	15	934.79	0.344
A4.2S-15-H6	4000	0.2	15	692.25	0.463
A5.2S-15-H6	5000	0.2	15	595.66	0.586
A6.2S-15-H6	6000	0.2	15	492.84	0.712
A7.2S-15-H6	7000	0.2	15	401.22	0.640
A8.2S-15-H6	8000	0.2	15	357.13	0.846

Table 2.12 : Effect of Sinusoidal Load Distribution on the Behaviour of Circular Arch

MODEL DESIGNATION	DIA (mm)	ϕ (DEG)	Pu (kn)	% δ
C2S-H1	2000	0	63.96	1.504
C3S-H1	3000	0	43.2	2.746
C4S-H1	4000	0	31.2	3.524
C5S-H1	5000	0	22.8	4.261
C6S-H1	6000	0	18.24	5.333
C7S-H1	7000	0	15.96	5.878
C8S-H1	8000	0	12.16	7.196
C2S-H2	2000	0	103.32	1.600
C3S-H2	3000	0	67.2	2.283
C4S-H2	4000	0	51.2	3.271
C5S-H2	5000	0	39.0	3.677
C6S-H2	6000	0	31.92	4.391
C7S-H2	7000	0	26.6	5.174
C8S-H2	8000	0	24.32	5.928
C2S-H3	2000	0	144.32	1.436
C3S-H3	3000	0	93.6	2.003

Table 2.12 continued...

MODEL DESIGNATION	DIA (mm)	ϕ (DEG)	Pu (kn)	% δ
C4S-H3	4000	0	70.4	2.992
C5S-H3	5000	0	54.6	3.340
C6S-H3	6000	0	45.6	3.7256
C7S-H3	7000	0	37.24	4.662
C8S-H3	8000	0	35.52	4.955
C2S-H4	2000	0	190.24	1.328
C3S-H4	3000	0	124.8	1.826
C4S-H4	4000	0	92.8	2.674
C5S-H4	5000	0	74.1	2.983
C6S-H4	6000	0	59.28	3.38
C7S-H4	7000	0	53.2	3.985
C8S-H4	8000	0	41.44	4.407
C2S-H5	2000	0	231.24	1.187
C3S-H5	3000	0	154.98	1.985
C4S-H5	4000	0	112.0	2.262
C5S-H5	5000	0	89.7	2.624
C6S-H5	6000	0	72.96	2.991
C7S-H5	7000	0	63.84	3.575
C8S-H5	8000	0	54.72	4.22

Table 2.12 continued...

MODEL DESIGNATION	DIA (mm)	ϕ (DEG)	Pu (kn)	% δ
C2S-H6	2000	0	354.24	1.020
C3S-H6	3000	0	238.62	1.535
C4S-H6	4000	0	172.8	1.862
C5S-H6	5000	0	140.0	2.599
C6S-H6	6000	0	112.32	2.674
C7S-H6	7000	0	95.76	2.922
C8S-H6	8000	0	85.12	3.412

APPENDIX
PROGRAM LISTING

```
C            PROGRAM S4 :    STEEL SET SUPPORT SYSTEMS
C
C     NONLINEAR FINITE ELEMENT PROGRAM FOR THE ANALYSIS OF STEEL
C     ARCH SUPPORT SYSTEMS USED IN UNDERGROUND TUNNELS
C
C
C                              DEVELOPED BY
C
C                 DR. HANI S. MITRI AND DR. FERRI P. HASSANI
C              DEPARTMENT OF MINING AND METALLURGICAL ENGINEERING
C                              MCGILL UNIVERSITY
C                         MONTREAL, QUEBEC   H3A 2A7
C
C  JUNE 1989
C
C THIS PROGRAM IS DEVELOPED UNDER CONTRACT NUMBER 63SS.23440-7-9054
C WITH DEPARTMENT OF SUPPLY AND SERVICES CANADA.
C
C  SCIENTIFIC AUTHORITY : DR. T.R. ASTON, EMR, CANMET-CRL, SYDNEY, N.S.
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      INTEGER*2 NLMV
      DIMENSION IA(1),TITLE(20)
      REAL*4 A
      COMMON NTOT,NFIRST,NLAST,A(9999)
      EQUIVALENCE (A(1),IA(1))
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/THREE/E,ET,SIGY,SIGU
      COMMON/FOUR/XD(100),YD(100),ICOD(2,100)
      COMMON/FIVE/NSTP,NLTP,NSGE,NE1,ALFA,CITA,NE6
      COMMON/SIX/NLMV,D,H
      CHARACTER*18  STP(6),DTP(5)
      CHARACTER*35 FILEIN,FILE2,FILE4
      LOGICAL FEXIST
      EXTERNAL OUPUTF
C*****  CONTROL STORAGE ON NEXT LINE   AND  LINE 5  AS WELL
      NTOT=9999
      DO 1 I=1,NTOT
 1    A(I)=0.0
      NSTR=0
      NTPI=5
      NTPO=6
      NTP1=17
      NTP2=8
      NTP3=9
      NTP4=10
      NTP5=11
      NTP6=12
```

```
      NTP7=13
      NTP8=14
      IDB=2
         WRITE(*,'(A)') '    PROGRAM S4 : STEEL SET SUPPORT SYSTEMS'
         WRITE(*,'(A)') '    DR. H.S.MITRI AND DR. F.P. HASSANI'
         WRITE(*,'(A)') '    DEPARTMENT OF MINING & MET. ENG.'
         WRITE(*,'(A)') '    MCGILL UNIVERSITY, MONTREAL, QUEBEC H3A 2A7'
         WRITE(*,'(A)') '    '
         WRITE(*,'(A)') '    CONTRACT NO. 63SS.23440-7-9054 WITH THE  '
         WRITE(*,'(A)') '    DEPARTMENT OF SUPPLY AND SERVICES CANADA.'
         WRITE(*,'(A)') '    SCIENTIFIC AUTHORITY : DR. T. R. ASTON'
         WRITE(*,'(A)') '    EMR, CANMET- CRL, SYDNEY, N.S.'
         WRITE(*,'(A)') '    JUNE 1989'
         WRITE(*,'(A)') '  '
         WRITE(*,'(A)') '  '
         WRITE(*,'(A,\)') '    ENTER DATAFILE NAME :  '
         READ(*,'(A)') FILEIN
         CALL OUPUTF(FILEIN,FILE2,FILE4)
         OPEN(NTPO,FILE=FILE4,STATUS='NEW')
C        OPEN(NTP6,FILE=FILE1,STATUS='NEW')
         OPEN(NTP7,FILE=FILE2,STATUS='NEW')
C        OPEN(NTP8,FILE=FILE3,STATUS='NEW')
         OPEN(NTPI,FILE=FILEIN,STATUS='OLD')
         OPEN(NTP1,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
         OPEN(NTP2,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
         OPEN(NTP3,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
         OPEN(NTP4,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
         OPEN(NTP5,ACCESS='SEQUENTIAL',FORM='UNFORMATTED')
C
C    NTP1 :  ELEMENT STRAIN MATRIX
C    NTP2 :  ELEMENT STIFFNESS MATRIX
C    NTP3 :  ELEMENT STRESSES, STRAINS AND COMPLIANCE MATRIX
C    NTP4 :  ELEMENT STRESSES, STRAINS AND COMPLIANCE MATRIX
C    NTP5 :  ELEMENT STIFFNESS MATRIX (NONLINEAR ANALYSIS)
   10  CONTINUE
       NVR =3
       WRITE(NTPO,2010)
       READ (NTPI,2000)TITLE
       WRITE(NTPO,2001)TITLE
       READ (NTPI,  * )NPROB,MODE,NO,NE,NSTP,NLTP,NSGE
       IF(MODE.NE.0)THEN
       IF(MODE.NE.3)STOP
       ELSE
       WRITE(NTPO,2020)NPROB,MODE
       WRITE(NTPO,2030)NO,NE
       ENDIF
       STP(1)='GENERAL STRUCTURE'
       STP(2)='SEMICIRCLE       '
       STP(3)='ARCH             '
       STP(4)='SPLAY ARCH       '
       STP(5)='CIRCLE           '
       STP(6)='CIRCLE           '
```

```
      DTP(1)='GENERAL LOAD     '
      DTP(2)='UNIFORM LOAD     '
      DTP(3)='SINUSOIDAL LOAD  '
      DTP(4)='PRESSURE  LOAD   '
      DTP(5)='CONCENTRATED LOAD'
      WRITE(NTPO,3000) STP(NSTP+1),DTP(NLTP+1),NSGE
      N1=1
      N2=N1+NVR*NO
      N3=N2+NVR*NO
      N4=N3+NO*IDB
      N5=N4+NO*IDB
      N6=N5+NE*5
      N7=N6+NE*3*IDB
      N8=N7+NE*3*IDB
      N9=N8+NSGE*4*IDB
      CITA=1.0
C     CALL INPUT(  JX ,  IX ,  X  ,  Y  , ICO , THIC, WID ,BTDT)
      CALL INPUT(A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8))
      READ (NTPI,  * )NLW
      NLC=0
      WRITE(NTPO,2040)
      WRITE(NTPO,2070)NLW
C******** CONVERT PERCENTAGE OF CROWN LENGTH TO NUMBER OF PROPORTIONAL**
C ***************************** LOADED ELEMENTS ************************
      READ (NTPI, *  )NLMV
      NLMC=0
      IF(NLTP.NE.0) THEN
      WRITE(NTPO,2076)NLMV
      IF(NSTP.EQ.3.AND.NLMV.EQ.100) THEN
      NLMV=NE
      ELSE
      NTT=NE1
      IF(NSTP.EQ.3) NTT=NE1+NE6
      IF(NSTP.EQ.5) NTT=NE/2
      RNLMV=NLMV/100.0*NTT
      IF((RNLMV-NLMV*NTT*100).LT.0.5) THEN
      NLMV=INT(RNLMV)
      ELSE
      NLMV=INT(RNLMV)+1
      END IF
      END IF
      ELSE
      WRITE(NTPO,2075)NLMV
      ENDIF
      N10=N9+NEQ*IDB
      N11=N10+NEQ*IDB
      N12=N11+NLW
      N13=N12+NLC
C     CALL LOADS(  RW  ,  RC  , NOW  , NOC  ,  JX ,NLW,NLC,NEQ,NVR,
C       X  ,  Y  ,  ICO , NLMV,NLMC)
      CALL LOADS(A(N9),A(N10),A(N11),A(N12),A(N1),NLW,NLC,NEQ,NVR,
     $A(N3),A(N4),A(N5),NLMV,NLMC)
```

```
      WRITE(NTPO,2002)
      CALL MGPROP
C     write(NTP6,2145) ALFA,CITA
C     write(NTP6,2146) NE,NO,NSTP,NLTP,NE1,NE6,SIGY
C     write(NTP6,2147)  (XD(I),I=1,NO),(YD(I),I=1,NO)
      IF(MODE.EQ.0)STOP
      N14=N13+NEQ+1
      N15=N14+NEQ
      N16=N15+6
      N17=N16+36*IDB
      IF(N17.GT.NTOT)CALL ERROR(N17)
      IF(N17.GT.NSTR)NSTR=N17
C     CALL ELEMD(  JX ,  X  ,  Y  , ICO ,THIC , WID ,MDIA,MHT,LJ,T)
      CALL ELEMD(A(N1),A(N3),A(N4),A(N5),A(N6),A(N7),A(N13),A(N14),
     $A(N15),A(N16))
C     REARRANGE DYNAMIC STORAGE
C     RETAIN JX,RW,RC,NOW,NOC,MDIA
C            1 , 2 ,3 ,4 , 5 , 6
C
      NMOVE=NEQ*2*IDB+NLW+NLC+NEQ+1
      DO 20 I=1,NMOVE
   20 A(N2+I-1)=A(N9+I-1)
      N3=N2+NEQ*IDB
      N4=N3+NEQ*IDB
      N5=N4+NLW
      N6=N5+NLC
      N7=N6+NEQ+1
      NA1=N7
      NA2 =NA1 +IDB*NMT
      NA3 =NA2 +IDB*NEQ
      NA4 =NA3 +IDB*3
      NA5 =NA4 +IDB*3
      NA6 =NA5 +IDB*7
      NA7 =NA6 +IDB*7
      NA8 =NA7 +IDB*21
      NA9 =NA8 +IDB*6
      NA10=NA9 +IDB*36
      NA11=NA10+IDB*36
      NA12=NA11+IDB*36
      NA13=NA12+IDB*6
      NA14=NA13+IDB*126
      NA15=NA14+6
      IF(NA15.GT.NTOT)CALL ERROR(NA15)
      IF(NA15.GT.NSTR)NSTR=NA15
C     CALL ASSMBL(MDIA , GS   ,  GL  ,   X  ,  WX  ,  Z   ,  WZ
      CALL ASSMBL(A(N6),A(NA1),A(NA2),A(NA3),A(NA4),A(NA5),A(NA6)
     @,A(NA7),A(NA8),A(NA9),A(NA10),A(NA11),A(NA12),A(NA13),A(NA14))
C        D   ,  FL  ,  TE  ,  WK   , ST    ,  BS   ,  BT   ,LJ)
      DO 30 I=NA2,NA15
   30 A(I)=0.0
      N8=NA2
      N9=N8+NEQ*IDB
```

```
      N10=N9+NEQ*IDB
      NEQ2=NEQ*2
      CALL COPY(A(N2),A(N8),NEQ2)
   42 CALL COLSOL(A(N7),A(N8),A(N6),NEQ,NMT,1)
      IF(NLC.GT.0.OR.NLMC.GT.0)CALL COLSOL(A(N7),A(N9),A(N6),NEQ,NMT,2)
      IF(MODE.GT.1)GO TO 44
      FAC=1.0
      CALL ELIM(FAC,A(N1),A(N2),A(N3),A(N8),A(N9),A(N4),NLW,A(N10))
C     CALL ELIM(FAC,  JX ,  RW ,  RC ,  DW ,  DC , NOW ,NLW, DISP)
      NF1=N10
      NF2=NF1+36*IDB
      NF3=NF2+36*IDB
      NF4=NF3+6
      NF5=NF4+6*IDB
      NF6=NF5+6*IDB
      NF7=NF6+6*IDB
      IF(NF7.GT.NTOT)CALL ERROR(NF7)
      CALL FORCES(A(N8),A(NF1),A(NF2),A(NF3),A(NF4),A(NF5),A(NF6))
C     CALL FORCES(  DT ,  ST  ,  T   ,  LJ  ,  U   ,  FL  ,  FG  )
      GO TO 10
   44 CONTINUE
      N15=N10+126*IDB
      N16=N15+21*IDB
      N17=N16+21*IDB
      N18=N17+21*IDB
      N19=N18+21*IDB
      N20=N19+21*IDB
      N21=N20+6
      N22=N21+36*IDB
      IF(N22.GT.NTOT)CALL ERROR(N22)
      IF(N22.GT.NSTR)NSTR=N22
      FAC=1000000.0
C     CALL FACTOR(  DW ,  DC ,FAC,   BT ,  EW  ,  EC  ,  SW  ,
      CALL FACTOR(A(N8),A(N9),FAC,A(N10),A(N15),A(N16),A(N17),
     $A(N18),A(N19),A(N20),A(N21),NLC,NLMC)
C        SC  , DEL ,  LJ  ,  TE  ,NLC,NLMC)
C     CLEAR STORAGE
C
      DO 50 I=N10,N22
   50 A(I)=0.0
      WRITE(NTPO,2050)FAC
      N11=N10+NMX*IDB
      IF (N11.GT.NTOT) CALL ERROR(N11)
C     CALL ELIM(FAC,  JX ,  RW ,  RC ,  DW  ,  DC  , NOW ,NLW,WK
      CALL ELIM(FAC,A(N1),A(N2),A(N3),A(N8),A(N9),A(N4),NLW,
     $A(N10))
C
      N11=N10+NEQ*IDB
      N12=N11+NEQ*IDB
      N13=N12+NMX*IDB
      IF(N13.GT.NTOT)CALL ERROR(N13)
      IF(N13.GT.NSTR)NSTR=N13
```

```
C     WRITE(NTPO,2080)NSTR
   5  IF(MODE.EQ.2)GO TO 10
C     CALL       NONLIN(JX,PE,PT,NOW,NLW,MDIA,GS,DT,RT,DR,RR,FI
      CALL NONLIN(A(N1),A(N2),A(N3),A(N4),NLW,A(N6),A(N7),A(N8),
     $A(N9),A(N10),A(N11),A(N12))
C     write(NTP6,2147)  (XD(I),I=1,NO),(YD(I),I=1,NO)
C     write(NTP6,2153) NLMV,D,H
C************************ F O R M A T ********************************
 2000 FORMAT(20A4)
 2001 FORMAT(5X,16HPROBLEM TITLE : ,10A4,/,21X,10A4)
 2002 FORMAT(5X,74(1H*))
 2003 FORMAT(5X,27(1H*),5X,11HEND OF DATA,5X,26(1H*),//)
 2010 FORMAT(5X,23(1H*),9X,11HPROGRAM  S4,9X,22(1H*),/,
     $5X,11(1H*),3X,46HNONLINEAR ANALYSIS OF STEEL SET SUPPOT SYSTEMS,
     $3X,11(1H*),/,41X,2HBY,/,
     $5X,13(1H*),10X,'H.S. MITRI AND F.P. HASSANI',10X,13(1H*),/,
     $5X,16(1H*),12X,17HMCGILL UNIVERSITY,12X,16(1H*),/,
     $5X,16(1H*),10X,22HMONTREAL, QUEBEC, 1989,10X,16(1H*),/,
     $5X,74(1H*),/,
     $5X,34HDSS CONTRACT NO. 63SS.23440-7-9054,/,
     $5X,74(1H*),////)
 2020 FORMAT(5X,19HPROBLEM NUMBER      ,I5,/,
     $       5X,19HEXECUTION MODE      ,I5)
 2030 FORMAT(5X,19HTOTAL NODES       = ,I5,/,
     $       5X,19HTOTAL ELEMENTS    = ,I5,/)
 2040 FORMAT(5X,23(1H*),5X,17HINITIAL LOAD DATA,5X,22(1H*))
 2050 FORMAT(5X,16(1H*),5X,'SOLUTION FOR LOAD INCREMENT NO.1',5X,16(1H*)
     $,///   5X,19HREFERENCE LOAD    = ,F10.4,' X  INITIAL LOAD',/)
 2060 FORMAT(5X,I4,5X,4F11.5)
 2070 FORMAT(5X,40HNO. OF NODES UNDER CONCENTRATED LOAD =  ,I5,/)
 2075 FORMAT(5X,40HNO. OF ELEMENTS UNDER DISTRIB. LOAD  =  ,I5,/)
 2076 FORMAT(5X,'% LOADED OF PROJECTED CROWN LENGTH   =  ',I5,/)
C2080 FORMAT(5X,40HREQUIRED DYNAMIC STORAGE              =  ,I8)
 3000 FORMAT(5X,'STRUCTURE TYPE    =',A18,/,5X,'LOAD TYPE         =',
     #    A18,/5X,'NUMBER OF SECTIONS=',I5,/)
 2145 format(2e15.6)
 2146 format(6i5,e15.6)
 2147 format(5e15.6)
 2153 format(i5,2e15.6)
C*********************************************************************
      END
      SUBROUTINE ASSMBL(MDIA,GS,GL,X,WX,Z,WZ,D,FL,TE,WK,STL,BS,BL,LJ)
C*********************************************************************
C     A  ROUTINE TO COMPUTE INDIVIDUAL ELEMENT STIFFNESS MATRICES AND  *
C     ASSEMBLE THEM IN A SKYLINED GLOBAL MATRIX                        *
C*********************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/THREE/E,ET,SIGY,SIGU
      DIMENSION MDIA(1),GS(1),GL(1),X(1),WX(1),Z(1),WZ(1),D(1),FL(1)
```

```
      DIMENSION TE(6,1),WK(6,1),STL(6,1),BS(1),BL(1),LJ(1),TH(3),WD(3)
     @,GG(6,6),GGT(108)
      REWIND NTP1
      REWIND NTP2
      REWIND NTP3
      CALL PSET(GS,NMT)
      CALL PSET(GL,NEQ)
      CALL PSET(FL,6)
      CALL PRELIM(WX,X,D,WZ)
      DO 40 IE=1,NE
      READ (NTP3)(LJ(J),J=1,6),AA,IT,IS,IF,WD,TH,((TE(K,L),K=1,6)
     1,L=1,6)
      IF(IS.EQ.0)GO TO 20
      CALL STIFF2(STL,AA,TH,WD,WX,X,D,TE,WK,IT,IS,BL,BS,WZ)
   20 CALL SETUP3(GS,GL,MDIA,STL,LJ,6,FL)
        DO 912 LL=1,3
        CALL GEOM(GG,X(LL),AA)
        DO 912 I=1,6
        DO 912 J=1,6
        KK=(I-1)*6+J+36*(LL-1)
        GGT(KK)=GG(I,J)
912     CONTINUE
        WRITE(NTP1) (BL(J),J=1,126),(GGT(I),I=1,108)
      WRITE(NTP2)((STL(K,L),K=1,6),L=1,6),(LJ(J),J=1,6),AA,WD,TH,
     $((TE(K,L),K=1,6),L=1,6),IT,IF
   40 CONTINUE
      RETURN
      END
      SUBROUTINE BEENL(BNL,U,GG)
C&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
C     A ROUTINE TO CALCULATE THE NONLINEAR STRAIN MATRIX BNL      &
C&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION BNL(126),GG(108),U(6)
      DO 5 I=1,3
      DO 5 J=1,7
      NPT=(I-1)*7+J
      DO 10 K=1,6
      KLM=(NPT-1)*6+K
      BNL(KLM)=0.0
      DO 10 L=1,6
      LMN=36*(I-1)+(K-1)*6+L
      BNL(KLM)=BNL(KLM)+U(L)*GG(LMN)
10    CONTINUE
5     CONTINUE
      RETURN
      END
      SUBROUTINE COLSOL(A,V,MAXA,NN,NWK,KKK)
C*********************************************************************
C       PROGRMAM TO SOLVE FINITE ELEMENT STATIC EQUILIBRIUM EQUATIONS
C       IN CORE, USING A COMPACTED STORAGE AND COLUMN REDUCTION SCHEME.
```

```
C INPUT VARIABLES:  A(NWK)=STIFFNESS MATRIX IN COMPACTED FORM
C                   V(NN) =RHS LOAD VECTOR
C
C                   MAXA(NNM)=VECTOR CONTAINING ADDRESSES OF DIAGONAL
C                             ELEMENTS
C                   NN=NUMBER OF EQUATIONS
C                   NWK=NUMBER OF ELEMENTS BELOW SKYLINE OF MATRIX
C                   KKK=INPUT FLAG
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION A(1),V(1),MAXA(1)
      NNM=NN+1
C          PERFORM L*D*L(T) FACTORIZATION OF STIFFNESS MATRIX
      IF(KKK-2) 40,150,150
   40  DO 140 N=1,NN
      KN=MAXA(N)
      KL=KN+1
      KU=MAXA(N+1) -1
      KH=KU-KL
      IF(KH) 140,90,50
   50 K=N-KH
      IC=0
      KLT=KU
      DO 80 J=1,KH
      IC=IC+1
      KLT=KLT-1
      KI=MAXA(K)
      ND=MAXA(K+1)-KI-1
      IF(ND) 80,80,60
   60 KK=MIN0(IC,ND)
      C=0.0
      DO 70 L=1,KK
   70 C=C+A(KI+L)*A(KLT+L)
      A(KLT)=A(KLT)-C
   80 K=K+1
   90 K=N
      B=0.0
      DO 100 KK=KL,KU
      K=K-1
      KI=MAXA(K)
      C=A(KK)/A(KI)
      B=B+C*A(KK)
  100 A(KK)=C
      A(KN)=A(KN)-B
  110 IF(A(KN)) 120,120,140
  120 WRITE(6,2000) N,A(KN)
      RETURN
  140 CONTINUE
CREDUCE RHS LOAD VECTOR
  150 DO 180 N=1,NN
      KL=MAXA(N) + 1
```

```
      KU=MAXA(N+1) - 1
      IF(KU-KL) 180,160,160
  160 K=N
      C=0.0
      DO 170 KK=KL,KU
      K=K-1
  170 C=C+A(KK)*V(K)
      V(N)=V(N)-C
  180 CONTINUE
C     BACKSUBSTITUTE
      DO 200 N=1,NN
      K=MAXA(N)
  200 V(N)=V(N)/A(K)
      IF(NN.EQ.1) RETURN
      N=NN
      DO 230 L=2,NN
      KL=MAXA(N) + 1
      KU=MAXA(N+1) - 1
      IF(KU-KL) 230,210,210
  210 K=N
      DO 220 KK=KL,KU
      K=K-1
  220 V(K)=V(K)-A(KK)*V(N)
  230 N=N-1
      RETURN
 2000 FORMAT(//,5X,'STOP-STIFFNESS MATRIX IS NOT POSITIVE DEFINITE
     +',//,5X,'NONPOSITIVE PIVOT FOR EQUATION',I5,//,5X,'PIVOT=',E20.12)
      END
      SUBROUTINE COLHT(MHT,NVEL,LJ)
C*******************************************************************************
C      A ROUTINE TO CALCULATE THE COLUMN HEIGHTS OF A MATRIX
C*******************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION MHT(1),LJ(1)
      LS=10000000
      DO 100 I=1,NVEL
      IF(LJ(I)) 110,100,110
  110 IF(LJ(I)-LS) 120,100,100
  120 LS=LJ(I)
  100 CONTINUE
      DO 200 I=1,NVEL
      II=LJ(I)
      IF(II.EQ.0) GO TO 200
      ME=II-LS
      IF(ME.GT.MHT(II)) MHT(II)=ME
  200 CONTINUE
      RETURN
      END
      SUBROUTINE COPY (O,C,N)
C*******************************************************************************
C     A ROUTINE TO COPY ARRAY O ONTO ARRAY C
```

```
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION O(1),C(1)
      DO 1 I=1,N
    1 C(I)=O(I)
      RETURN
      END
      SUBROUTINE DIAADD(MDIA,MHT,NNET,MK,NVA)
C*************************************************************************
C     A ROUTINE TO CALCULATE THE DIAGONAL ELEMENT ADDRESSES OF A SKY-
C     LINED MATRIX
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION MDIA(1),MHT(1)
      NN=NNET+1
      DO 20 I=1,NN
   20 MDIA(I)=0
      MDIA(1)=1
      MDIA(2)=2
      MK=0
      IF(NNET.EQ.1) GO TO 100
      DO 10 I=2,NNET
      IF(MHT(I).GT.MK) MK=MHT(I)
   10 MDIA(I+1)=MDIA(I)+MHT(I)+1
  100 MK=MK+1
      NVA=MDIA(NN)-MDIA(1)
      RETURN
      END
      SUBROUTINE ELEMD(JX,X,Y,ICO,THC,WID,MDIA,MHT,LJ,T)
C*************************************************************************
C     A ROUTINE TO COMPUTE THE RELEVANT ELEMENT DATA AND STORE ON DISCS
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION JX(1),X(1),Y(1),ICO(5,1),WID(3,1),THC(3,1),MDIA(1),
     $MHT(1),LJ(1),T(6,1),WD(3),TH(3)
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      REWIND NTP3
      DO 10 IE=1,NE
      CALL ELJ(ICO,5,IE,3,2,JX,NMX,NE,6,LJ)
      I1=ICO(1,IE)
      I2=ICO(2,IE)
      I3=ICO(3,IE)
      I4=ICO(4,IE)
      I5=ICO(5,IE)
      AA=((X(I2)-X(I1))**2+(Y(I2)-Y(I1))**2)**0.50
      CC=(X(I2)-X(I1))/AA
      SS=(Y(I2)-Y(I1))/AA
      DO 1 L=1,3
```

```
      TH(L)=THC(L,IE)
    1 WD(L)=WID(L,IE)
      CALL PRESET(T,6,6)
      T(1,1)=CC
      T(1,2)=SS
      T(2,1)=-T(1,2)
      T(2,2)=T(1,1)
      T(3,3)=1.0
      DO 5 M=1,3
      DO 5 J=1,3
    5 T(M+3,J+3)=T(M,J)
      CALL COLHT(MHT,6,LJ)
      WRITE(NTP3)(LJ(J),J=1,6),AA,I3,I4,I5,WD,TH,((T(K,L),K=1,6)
     1,L=1,6)
   10 CONTINUE
      CALL DIAADD(MDIA,MHT,NEQ,LBMAX,NMT)
      WRITE(NTPO,20)
C     WRITE(NTPO,30)NEQ,NMT,LBMAX
   20 FORMAT(4X,75(1H*),/)
   30 FORMAT(5X,'NO. OF EQUATIONS =',I5,/,
     @       5X,'MATRIX SIZE      =',I5,/,
     @       5X,'MAX COL HEIGHT   =',I5,//)
      RETURN
      END
      SUBROUTINE ELIM(FAC,JX,RW,RC,DW,DC,NOW,NLW,DISP)
C*****************************************************************************
C   A ROUITNE TO COMPUTE AND PRINT ELASTIC LIMIT LOAD & DISPLACEMENTS*
C                    AND UPDATE NODAL COORDINATES *
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/FOUR/ XD(100),YD(100),ICOD(2,100)
      DIMENSION JX(1),RW(1),RC(1),DW(1),DC(1),NOW(1)
     $,DISP(1)
      DO 10 I=1,NEQ
      DW(I)=FAC*DW(I)+DC(I)
      RW(I)=FAC*RW(I)
      RC(I)=RW(I)+RC(I)
   10 CONTINUE
      IF(NLW.GT.0)WRITE(NTPO,30)
      DO 20 I=1,NLW
      N=NOW(I)
      M1=NVR*(N-1)+1
      M2=M1+NVR-1
      KK=0
      DO 15 J=M1,M2
      KK=KK+1
      DISP(KK)=0.0
      JJ=JX(J)
      IF(JJ.EQ.0)GO TO 15
```

```
      DISP(KK)=RW(JJ)
   15 CONTINUE
      WRITE(NTPO,40)N,(DISP(J),J=1,NVR)
   20 CONTINUE
      WRITE(NTPO,70)
      DO 24 I=1,NO
      M1=(I-1)*NVR+1
      M2=M1+NVR-1
      KK=0
      DO 22 J=M1,M2
      KK=KK+1
      DISP(KK)=0.0
      JJ=JX(J)
      IF(JJ.EQ.0)GO TO 22
      DISP(KK)=DW(JJ)
   22 CONTINUE
   24 WRITE(NTPO,40)I,(DISP(J),J=1,NVR)
   30 FORMAT(//,5X,'REFERENCE LOADS',//
     $,5X,'NODE',7X,'FX',8X,'FY',8X,'MX'//)
   40 FORMAT(5X,I5,3E15.5)
   70 FORMAT(//,5X,'NODAL DISPLACEMENTS',//,
     $5X,'NODE',8X,'X-DIR',10X,'Y-DIR',10X,'ROT',/)
      DO 75 I=1,NMX
      J=JX(I)
      DISP(I)=0.0
      IF(J.GT.0) DISP(I)=DW(J)
75    CONTINUE
      DO 80 I=1,NO
      IX=(I-1)*3+1
      IY=IX+1
      XD(I)=XD(I)+DISP(IX)
      YD(I)=YD(I)+DISP(IY)
80    CONTINUE
      write(NTP7,2148) FAC,DISP(2)
 2148 format(2e15.6)
      RETURN
      END
C
      SUBROUTINE ELJ(ICO,NICO,IE,NVR,NNODEL,JX,NMX,NELEM,NLJ,LJ)
C*************************************************************************
C      A ROUTINE TO BUILD ELEMENT CONNECTIVITY ARRAY
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION LJ(NLJ),JX(NMX),ICO(NICO,NELEM)
      DO 2 J=1,NNODEL
      J1=(J-1)*NVR
      J2=(ICO(J,IE)-1)*NVR
      DO  1 I=1,NVR
    1 LJ(I+J1)=JX(J2+I)
    2 CONTINUE
      RETURN
```

```
      END
      SUBROUTINE ERROR(N)
C*************************************************************************
C      A ROUTINE TO REPORT ERROR MESSAGE FOR INSUFFICIENT STORAGE
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      WRITE(NTPO,100)N
  100 FORMAT(5X,'INSUFFICIENT DYNAMIC STORAGE AVAILABLE',/,
     $       5X,'MAIN ARRAY SIZE SHOULD BE     ',I10,/)
      STOP
      END
      SUBROUTINE FACTOR(DW,DC,FAC,BL,EW,EC,SW,SC,DEL,LJ,TE,NLC,NLMC)
C*************************************************************************
C     A ROUTINE TO CONTROL THE SEARCH FOR MAXIMUM STRESS AND PERFORM
C     THE SCALING OF STRESSES AND STRAINS
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/THREE/PR1,PR2,PR3,PR4
      DIMENSION DW(1),DC(1),EW(1),EC(1),BL(1),SW(1),SC(1),DEL(1),
     $LJ(1),TE(6,1),TH(3),WD(3),GGT(108)
      REWIND NTP1
      REWIND NTP3
      REWIND NTP4
C
      DO 10 I=1,21
   10 DEL(I)=PR1
      FAC=1000000.
      DO 30 IE=1,NE
        READ (NTP1) (BL(J),J=1,126),(GGT(I),I=1,108)
      READ (NTP3)(LJ(J),J=1,6),AA,I3,I4,I5,WD,TH,((TE(K,L),K=1,6)
     1,L=1,6)
      IF(NLC.EQ.0.AND.NLMC.EQ.0)GO TO 20
      CALL STRESS(BL,DC,LJ,EC,SC,DEL,6,21,TE)
   20 CALL STRESS(BL,DW,LJ,EW,SW,DEL,6,21,TE)
      CALL FACTR(SW,SC,21,NLC,NLMC,FAC)
      WRITE(NTP4)(EW(J),J=1,21),(SW(J),J=1,21)
      IF(NLC.EQ.0.AND.NLMC.EQ.0)GO TO 30
      WRITE(NTP4)(EC(J),J=1,21),(SC(J),J=1,21)
   30 CONTINUE
      IF(FAC.LT.0.0)WRITE(NTPO,1100)FAC
      IF(FAC.LT.0.0)STOP
      REWIND NTP3
      REWIND NTP4
      DO 75 J=1,21
      EC(J)=0.0
   75 SC(J)=0.0
       FAC=FAC/5.0
```

```
      DO 90 IE=1,NE
      READ (NTP4)(EW(J),J=1,21),(SW(J),J=1,21)
      IF(NLC.EQ.0.AND.NLMC.EQ.0)GO TO 80
      READ (NTP4)(EC(J),J=1,21),(SC(J),J=1,21)
   80 DO 85 J=1,21
      EW(J)=EC(J)+FAC*EW(J)
   85 SW(J)=SC(J)+FAC*SW(J)
C     WRITE(NTPO,1000)IE,(SW(J),J=1,21)
      WRITE(NTP3)(EW(J),J=1,21),(SW(J),J=1,21),(DEL(J),J=1,21)
   90 CONTINUE
C1000 FORMAT(5X,'ELASTIC LIMIT STRESSES OF EL NO.',I2,/,3(7F10.4,/))
 1100 FORMAT(5X,'NEGATIVE ELASTIC LIMIT LOAD FACTOR OF ',F12.5,' HAS',
     $' BEEN CALCULATED.',/,5X,'SPECIFIED CONSTANT LOADS ARE SO HIGH'
     $,'THAT THEY INDUCE YIELDING.',/,5X,'REDUCE CONSTANT LOADS OR'
     $,'TREAT THEM AS INCREMENTAL.',/,5X,'PROGRAM STOPS HERE',//)
      RETURN
      END
      SUBROUTINE FACTR(SW,SC,M,N,K,FAC)
C*************************************************************************
C     A ROUTINE TO COMPUTE THE MAXIMUM STRESS WITHIN THE ELEMENT
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/THREE/E,ET,SIGY,SIGU
      DIMENSION SW(1),SC(1)
      DO 20 I=1,M
      EFFW=DABS(SW(I))
      EFFC=0.0
      IF(N.GT.0.OR.K.GT.0)EFFC=SC(I)
      IF(EFFW.LT.1.E-4)EFFW=1.E-4
      RAT=(SIGY-EFFC)/EFFW
      IF(RAT.LT.FAC)FAC=RAT
   20 CONTINUE
      RETURN
      END
      SUBROUTINE GEOM(GG,CITA,AL)
C#########################################################################
C       A ROUTINE TO CALCULATE THE GEOMETRICALLY NONLINEAR MATRIX  #
C#########################################################################
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION GG(6,6),G1(2,6)
      CALL PRESET (G1,2,6)
      CALL PRESET (GG,6,6)
      G1(1,1)=-1.0
      G1(1,4)=1.0
      G1(2,2)=6.0*CITA*(CITA-1.0)
      G1(2,3)=AL*(1.0-CITA)*(1.0-3.0*CITA)
      G1(2,5)=-G1(2,2)
      G1(2,6)=AL*CITA*(3.0*CITA-2.0)
      DO 30 I=1,6
      DO 30 J=1,6
```

```
      DO 30 K=1,2
      GG(I,J)=(G1(K,I)*G1(K,J))/AL**2+GG(I,J)
30    CONTINUE
      RETURN
      END
      SUBROUTINE INITK(AL,BFL,TFL,DWB,TWB,SIG,STGM,TE)
C#####################################################################
C   A ROUTINE TO CALCULATE THE INITIAL STIFFNESS MATRIX              #
C#####################################################################
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION SIG(21),W(3),XI(3),WZ(3),GG(6,6),STGM(6,6),TE(6,6)
     $,WK(6,6),STGL(6,6)
      CALL PRESET(STGL,6,6)
      W(1)=5.0/9.0
      W(2)=8.0/9.0
      W(3)=5.0/9.0
      DO 20 I=1,3
      XI(I)=0.5-(2-I)*(0.15)**0.5
20    CONTINUE
      WZ(1)=1.0
      WZ(2)=4.0
      WZ(3)=1.0
      DO 40 I=1,3
      CALL GEOM(GG,XI(I),AL)
      DO 40 J=1,9
      I1=7*(I-1)
      CONS=WZ(J)*SIG(I1+J)*TFL*BFL
      IF((J.GE.4).AND.(J.LE.6))  CONS=WZ(J-3)*SIG(I1+(J-1))*DWB*TWB
      IF(J.GE.7)       CONS=WZ(J-6)*SIG(I1+(J-2))*TFL*BFL
900   DO 50 M=1,6
      DO 50 N=1,6
      STGL(M,N)=STGL(M,N)+GG(M,N)*W(I)*AL*CONS/12.0
50    CONTINUE
40    CONTINUE
       CALL TRANS(STGL,TE,STGM,WK,6,6,1.0)
      RETURN
      END
      SUBROUTINE FORCES(D,ST,T,LJ,U,FL,FG)
C*********************************************************************
C     A ROUTINE TO COMPUTE THE ELEMENT INTERNAL FORCES
C*********************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      DIMENSION D(1),T(6,1),ST(6,1),LJ(1),U(1),FL(1),FG(1),WH(3),TH(3)
      REWIND NTP2
      WRITE(NTPO,200)
      WRITE(NTPO,220)
      DO 100 IEL=1,NE
      READ (NTP2)((ST(I,J),I=1,6),J=1,6),(LJ(J),J=1,6),AL,WH,TH,
```

```
     $((T(K,L),K=1,6),L=1,6),IT,IF
      IF(IF.EQ.0)GO TO 100
      DO 10 I=1,6
      II=LJ(I)
      U(I)=0.0
      IF(II.EQ.0)GO TO 10
      U(I)=D(II)
  10  CONTINUE
      DO 20 I=1,6
      FG(I)=0.0
      DO 20 J=1,6
      FG(I)=FG(I)+ST(I,J)*U(J)
  20  CONTINUE
      DO 30 I=1,6
      FL(I)=0.0
      DO 30 J=1,6
      FL(I)=FL(I)+T(I,J)*FG(J)
  30  CONTINUE
      WRITE(NTPO,240)IEL,(FL(K),K=1,6)
  100 CONTINUE
  200 FORMAT(//,5X,6HMEMBER,1X,8HINTERNAL,1X,6HFORCES,//)
  220 FORMAT(1X,'ELEMENT',16X,'FIRST NODE ',25X,' SECOND NODE',/,1X,
     $'NUMBER',2('       AXIAL          SHEAR          BENDING    '),/,
     $     11X,2('       FORCE          FORCE          MOMENT     '),/)
  240 FORMAT(2X,I4,2X,6E12.5)
      RETURN
      END
      SUBROUTINE LOADS(R,P,NOD,NOC,JX,NLW,NLC,NEQ,NVR,X,Y,ICO,MV,MC)
C*************************************************************************
C     A ROUTINE TO READ NODAL FORCES AND GENERATE LOAD VECTOR(S)
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/FIVE/NSTP,NLTP,NSGE,NE1,ALFA,CITA,NE6
      DIMENSION R(NEQ),P(NEQ),NOD(NLW),NOC(NLC),JX(1),X(1),Y(1),ICO(5,1)
      DIMENSION PM(6),PMG(6),JJ(6)
      DO 10 I=1,NEQ
      R(I)=0.0
  10  P(I)=0.0
      IF(NLW.EQ.0)GO TO 25
      WRITE(NTPO,500)
      DO 20 I=1,NLW
      READ(NTPI,*) NOD(I),FX,FY,BM
  55  WRITE(NTPO,510)NOD(I),FX,FY,BM
      L=NOD(I)
      K=(L-1)*NVR+1
      J1=JX(K)
      J2=JX(K+1)
      J3=JX(K+2)
      IF(J1.NE.0)R(J1)=R(J1)+FX
      IF(J2.NE.0)R(J2)=R(J2)+FY
```

```
      IF(J3.NE.0)R(J3)=R(J3)+BM
   20 CONTINUE
   25 IF(NLC.EQ.0)GO TO 40
      DO 30 I=1,NLC
      READ (NTPI, * )NOC(I),FX,FY,BM
      WRITE(NTPO,510)NOC(I),FX,FY,BM
      L=NOC(I)
      K=(L-1)*NVR+1
      J1=JX(K)
      J2=JX(K+1)
      J3=JX(K+2)
      IF(J1.NE.0)P(J1)=P(J1)+FX
      IF(J2.NE.0)P(J2)=P(J2)+FY
      IF(J3.NE.0)P(J3)=P(J3)+BM
   30 CONTINUE
C
   40 IF(MV.EQ.0)GO TO 42
C     WRITE(NTPO,520)
      WRITE(NTPO,530)
      MTYPE=1
      MUDL =MV
      GO TO 44
   42 IF(MC.EQ.0)GO TO 110
      WRITE(NTPO,550)
      WRITE(NTPO,530)
      MTYPE=2
      MUDL=MC
   44 DO 100 I=1,MUDL
      IF((NSTP.NE.0.AND.NLTP.NE.0).AND.NLTP.NE.4) THEN
      M=I
      IF(NLTP.EQ.1) THEN
      WXG=0.0
      WYG=-1.0
      ELSE IF(NLTP.EQ.2) THEN
      CITA=ALFA*3.1415927/180.0/NE1
      WXG=0.0
      WYG=-(DCOS((I-1)*CITA)+DCOS(I*CITA))/2.0
      IF(M.GT.NE1) WYG=-DCOS(ALFA*3.1415927/180.0)
      ELSE IF(NLTP.EQ.3) THEN
         IF(I.LE.NE1) THEN
      CITA1=(I-1)*CITA+CITA/2.0
      WXG=-DSIN(CITA1)
      WYG=-DCOS(CITA1)
         ELSE IF(NSTP.EQ.2) THEN
      WXG=-1.0
      WYG=0.0
      ELSE IF(NSTP.EQ.3) THEN
      WXG=-DSIN(ALFA*3.1415926/180.0)
      WYG=-DCOS(ALFA*3.1415926/180.0)
         END IF
      ENDIF
      ELSE
```

```
      READ(NTPI, * )M,WXG,WYG
      ENDIF
      I1=ICO(1,M)
      I2=ICO(2,M)
      I3=ICO(3,M)
      AL=((X(I1)-X(I2))**2+(Y(I2)-Y(I1))**2)**0.50
      CC=(X(I2)-X(I1))/AL
      SS=(Y(I2)-Y(I1))/AL
      WX= CC*WXG+SS*WYG
      WY=-SS*WXG+CC*WYG
      CALL PSET(PM,6)
      PM(1)=-WX*AL/2.0
      PM(4)=PM(1)
      PM(2)=-WY*AL/2.0
      PM(5)=PM(2)
      IF(I3.EQ.1)GO TO 70
      IF(I3.EQ.3)GO TO 50
      IF(I3.EQ.4)GO TO 60
      PM(3)=-WY*AL**2/12.0
      PM(6)=-PM(3)
      GO TO 70
   50 PM(2)=-3.0/8.0*WY*AL
      PM(5)=-5.0/8.0*WY*AL
      PM(3)=0.0
      PM(6)=WY*AL**2/8.0
      GO TO 70
   60 PM(2)=-5.0/8.0*WY*AL
      PM(5)=-3.0/8.0*WY*AL
      PM(3)=-WY*AL**2/8.0
      PM(6)=0.0
   70 PMG(1)=PM(1)*CC-PM(2)*SS
      PMG(2)=PM(1)*SS+PM(2)*CC
      PMG(3)=PM(3)
      PMG(4)=PM(4)*CC-PM(5)*SS
      PMG(5)=PM(4)*SS+PM(5)*CC
      PMG(6)=PM(6)
      WRITE(NTPO,540)M,WXG,WYG
      K=(I1-1)*NVR
      DO 90 N=1,2
      IF(N.EQ.2)K=(I2-1)*NVR
      DO 80 J=1,3
      L=(N-1)*3+J
      JJ(L)=JX(K+J)
      JJJ=JJ(L)
      IF(MTYPE.EQ.2)GO TO 79
      IF(JJJ.NE.0)R(JJJ)=R(JJJ)-PMG(L)
      GO TO 80
   79 IF(JJJ.NE.0)P(JJJ)=P(JJJ)-PMG(L)
   80 CONTINUE
   90 CONTINUE
  100 CONTINUE
      IF(MTYPE.EQ.1)GO TO 42
```

```
  500 FORMAT(5X,4HNODE,12X,2HFX,12X,2HFY,12X,2HBM,/)
  510 FORMAT(I10,3E15.5)
  520 FORMAT(5X,23(1H*),5X,17HELEMENT LOAD DATA,5X,23(1H*)//)
  530 FORMAT(5X,7HELEMENT,4X,'DISTRIBUTED   LOADS',/,5X,'NUMBER',5X,
     $'X-DIR',9X,'Y-DIR',//)
  540 FORMAT(5X,I4,3X,2F10.4)
  550 FORMAT(5X,8HELEMENTS,1X,4HWITH,1X,8HCONSTANT,1X,5HLOADS,//)
  110 RETURN
      END
      SUBROUTINE LODINC(R,DP,NP,M)
C*************************************************************************
C     A ROUTINE FOR AUTOMATIC CONTROL OF LOAD INCREMENT SIZE
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION DP(NP)
      IF(R.GT.0.90)RETURN
      IF(R.LE.0.90)DL=0.80
      IF(R.LE.0.80)DL=0.60
      IF(R.LE.0.70)DL=0.40
      IF(R.LE.0.60)DL=0.20
      MM=M+1
      DO 1 I=MM,NP
      IF(DL.GT.DP(I))GO TO 1
      DP(I)=DL
  1   CONTINUE
      RETURN
      END
      SUBROUTINE MGPROP
C*************************************************************************
C     A ROUTINE TO READ AND PRINT MATERIAL PROPERTIES
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/THREE/E,ET,SIGY,SIGU
      READ (NTPI,*) E,ET,SIGY,SIGU
      WRITE(NTPO,1)
      WRITE(NTPO,2)E,ET,SIGY,SIGU
  1   FORMAT(//,5X,23(1H*),5X,19HMATERIAL PROPERTIES,5X,22(1H*))
  2   FORMAT(5X,'MODULUS OF ELASTICITY =',F10.3,
     $       3X,'TANGENT MODULUS       =',F10.3,/,
     $       5X,'YIELD STRESS          =',F10.3,
     $       3X,'ULTIMATE STRESS       =',F10.3,//)
      RETURN
      END
      SUBROUTINE NEWTR(IE,AL,TE)
C*************************************************************************
C   A ROUTINE TO UPDATE THE TRANSFORMATION MATRIX FOR AN ELMENT*
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
```

```
      COMMON/FOUR/ XD(100),YD(100),ICOD(2,100)
      DIMENSION TE(6,6)
      I1=ICOD(1,IE)
      I2=ICOD(2,IE)
      CC=(XD(I2)-XD(I1))/AL
      SS=(YD(I2)-YD(I1))/AL
      CALL PRESET(TE,6,6)
      TE(1,1)=CC
      TE(1,2)=SS
      TE(2,1)=-SS
      TE(2,2)=CC
      TE(3,3)=1.0
      DO 6 I=1,3
      DO 6 J=1,3
6     TE(I+3,J+3)=TE(I,J)
      RETURN
      END
      SUBROUTINE INPUT(JX,IX,X,Y,ICO,THC,WID,BTDT)
C*****************************************************************************
C     A ROUTINE TO READ AND PRINT NODE AND ELEMENT DATA                      *
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      INTEGER*2 NLMV
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/FIVE/NSTP,NLTP,NSGE,NE1,ALFA,CITA,NE6
      COMMON/FOUR/ XD(100),YD(100),ICOD(2,100)
      COMMON/SIX/NLMV,D,H
      DIMENSION JX(1),IX(1),X(1),Y(1),ICO(5,1),THC(3,1),WID(3,1),TH(3),
     $WD(3),BTDT(1,4)
      CHARACTER*5 DOF(2)
       NE6=0
      DOF(1)='FIXED'
      DOF(2)='FREE'
      CALL PSET(XD,100)
      CALL PSET(YD,100)
      DO 1986 II=1,2
      DO 1986 JJ=1,100
1986  ICOD(II,JJ)=0
      IF(NSTP.NE.0) THEN
      CALL AUTOCO(IX,X,Y)
      ELSE
      WRITE(NTPO,1000)
      WRITE(NTPO,1010)
      DO 10 I=1,NO
      I2=NVR*I
      I1=I2-NVR+1
      READ (NTPI,  * )M,X(I),Y(I),(IX(K),K=I1,I2)
      WRITE(NTPO,1020)I,X(I),Y(I),DOF(IX(I1)+1),DOF(IX(I1+1)+1),
     $DOF(IX(I2)+1)
      XD(I)=X(I)
```

```
      YD(I)=Y(I)
10    CONTINUE
      WRITE(NTPO,1021)
      ENDIF
      WRITE(NTPO,1030)
      WRITE(NTPO,1040)
      DO 1987 JJ=1,NSGE
1987  READ(NTPI,*) M,(BTDT(JJ,KK),KK=1,4)
      DO 20 I=1,NE
      IF(NSTP.NE.0) THEN
      ICO(1,I)=I
      ICO(2,I)=I+1
      ICO(3,I)=2
      ICO(4,I)=1
      ICO(5,I)=0
      ISEC=1
      IF(NSGE.NE.1) READ (NTPI,*) M,ISEC
      ELSE
      READ(NTPI,*) M,(ICO(K,I),K=1,4),ISEC
       ICO(5,I)=0
      ENDIF
      BFL=BTDT(ISEC,1)
      TFL=BTDT(ISEC,2)
      DWB=BTDT(ISEC,3)
      TWB=BTDT(ISEC,4)
      WRITE(NTPO,1050)I,(ICO(K,I),K=1,4),BFL,TFL,DWB,TWB
      DO 30 J=1,2
      ICOD(J,I)=ICO(J,I)
30    CONTINUE
      TH(1)=TFL
      TH(2)=DWB
      TH(3)=TFL
      WD(1)=BFL
      WD(2)=TWB
      WD(3)=BFL
      DO 15 L=1,3
      THC(L,I)=TH(L)
  15  WID(L,I)=WD(L)
  20  CONTINUE
      WRITE(NTPO,1021)
  75  NEQ=0
      NMX=NVR*NO
      DO 80 I=1,NMX
      JX(I)=0
      IF(IX(I).EQ.0)GO TO 80
      IF(IX(I).GT.1)GO TO 78
      NEQ=NEQ+1
      JX(I)=NEQ
      GO TO 80
  78  JX(I)=IX(I)
  80  CONTINUE
C************************ F O R M A T ****************************
```

```
 1000 FORMAT(5X,24(1H*),5X,16HNODAL POINT DATA,5X,24(1H*),/)
 1020 FORMAT(5X,I3,2F12.4,3X,A5,3X,A5,3X,A5)
 1021 FORMAT(5X,74(1H*),//)
 1010 FORMAT(5X,4HNODE,6X,7HX-COORD,2X,7HY-COORD,4X,7HDEGREES
     $11H OF FREEDOM,/,5X,6HNUMBER,24X,5HX-DIR,3X,5HY-DIR,3X,
     $8HROTATION,//)
 1030 FORMAT(5X,26(1H*),5X,12HELEMENT DATA,5X,26(1H*),/)
 1040 FORMAT(5X,7HELEMENT,3X,10HCONNECTING,2X,2HIT,2X,2HIS,
     $6X,6HFLANGE,15X,3HWEB,/,5X,6HNUMBER,6X,5HNODES,17X,5HWIDTH,
     $2X,9HTHICKNESS,2X,5HDEPTH,2X,9HTHICKNESS,/)
 1050 FORMAT(2X,I4,3X,2I5,5X,2I4,5X,2F8.3,5X,2F8.3)
      RETURN
      END
      SUBROUTINE AUTOCO(IX,X,Y)
C*****************************************************************************
C   A ROUTINE TO GENERATE COORDINATES AND BOUNDERY CONDITIONS OF THE   *
C            SPECIFIC TYPES OF STRUCTURES                              *
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      INTEGER*2 NLMV
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/FIVE/NSTP,NLTP,NSGE,NE1,ALFA,CITA,NE6
      COMMON/FOUR/XD(100),YD(100),ICOD(2,100)
      COMMON/SIX/NLMV,D,H
      DIMENSION IX(1),X(1),Y(1)
      CHARACTER*5 DOF(2)
      DOF(1)='FIXED'
      DOF(2)='FREE'
C   READ DIAMETER, HEIGHT AND SPLAY LEG ANGLE FROM HORIZONTAL
      READ (NTPI,*) D,H,ALFA
      WRITE(NTPO,190)
      WRITE(NTPO,200) D,H,ALFA
      WRITE(NTPO,1000)
      WRITE(NTPO,1010)
C  TO CALCULATE THE NUMBER OF ELEMENTS ON THE CURVED INTERVAL
      IF (NSTP.EQ.1.OR.NSTP.EQ.4.OR.NSTP.EQ.5) THEN
      NE1=NE
      ELSEIF(NSTP.EQ.2) THEN
      NE1=(3*NE)/4
      NE2=NE-NE1
      ELSE
      NE1=(3*NE)/4-1
      NE2=NE-NE1
      ENDIF
C  CITA IS THE ANGLE CORESPONDING TO EACH ELEMENT
      CITA=ALFA*3.1415927/180.0/NE1
      AF=1.0
      IF(NSTP.EQ.3) AF=ALFA*3.1415927/180.0
      IF(NSTP.EQ.2.OR.NSTP.EQ.3) THEN
C NE3,NE4 AND NE5 ARE THE NUMBERS OF ELEMENTS ON  THE STRAIGHT INTERVALS
```

```
      NE3=NE2/2
      NE4=NE2/3
      NE5=NE2-NE3-NE4
      HL=H-D/2.0
       if(nstp.eq.3) hl=h-d/2.0*(1-cos(af))
      HL1=HL/3.0
      AL3=HL1/NE3
      AL4=HL1/NE4
      AL5=HL1/NE5
      if(nstp.eq.3) ne6=d/2.0*cos(af)/al3
        hl=h-d/2.0
      ENDIF
      DO 10 I=1,NO
101   I2=NVR*I
      I1=I2-NVR+1
      IF(I.LE.(NE1+1)) THEN
      TCITA=(I-1)*CITA
      X(I)=SIN(TCITA)*D/2.0
      Y(I)=COS(TCITA)*D/2.0
      IF(NSTP.eq.2.or.nstp.eq.3) Y(I)=HL+Y(I)
      ELSEIF(NSTP.EQ.3) THEN
      IF(I.LE.(NE1+NE3+1)) THEN
      X(I)=X(I-1)+AL3/TAN(AF)
      Y(I)=Y(I-1)-AL3
      IF(I.NE.(NE1+ne6+1)) GOTO 105
      X(I)=D/2.0/SIN(AF)
      Y(I)=HL
105   CONTINUE
      ELSEIF(I.LE.NE1+NE3+NE4+1) THEN
      X(I)=X(I-1)+AL4/TAN(AF)
      Y(I)=Y(I-1)-AL4
      ELSE
      X(I)=X(I-1)+AL5/TAN(AF)
      Y(I)=Y(I-1)-AL5
      ENDIF
      ELSE if(nstp.eq.2) then
      X(I)=D/2.0
      Y(I)=Y(I-1)-AL4
      IF(I.LE.(NE1+NE3+1)) Y(I)=Y(I-1)-AL3
      IF(I.GT.NE1+NE3+NE4+1) Y(I)=Y(I-1)-AL5
      ENDIF
      m=no*nvr-2
      DO 20 K=I1,I2
      IX(K)=1
      IF(K.EQ.1.OR.K.EQ.3) IX(K)=0
      IF(K.ge.m) IX(K)=0
20    CONTINUE
        if(i.eq.no) then
        nt=no*nvr
       if(nstp.eq.1.or.nstp.eq.2.or.nstp.eq.3) ix(nt)=1
       if(nstp.eq.4) ix(m)=1
        end if
```

```
      WRITE (NTPO,1020) I,X(I),Y(I),DOF(IX(I1)+1),DOF(IX(I1+1)+1),
     $DOF(IX(I2)+1)
      XD(I)=X(I)
      YD(I)=Y(I)
10    CONTINUE
      WRITE(NTPO,1021)
190   FORMAT(5X,'GEOMETRY OF THE STRUCTURE',/)
200   FORMAT(5X,'DIAMETER   =',F10.4,/,5X,'HEIGHT     =',F10.4,/,5X,
     #    'SPLAY ANGLE=', F10.4)
 1000 FORMAT(5X,24(1H*),5X,16HNODAL POINT DATA,5X,24(1H*),/)
 1020 FORMAT(5X,I3,2F12.4,3X,A5,3X,A5,3X,A5)
 1021 FORMAT(5X,74(1H*),//)
 1010 FORMAT(5X,4HNODE,6X,7HX-COORD,2X,7HY-COORD,4X,7HDEGREES
     $11H OF FREEDOM,/,5X,6HNUMBER,24X,5HX-DIR,3X,5HY-DIR,3X,
     $8HROTATION,//)
      RETURN
      END




      SUBROUTINE NONLIN(JX,PE,PT,NOW,NLW,MDIA,GS,DT,RT,DR,RR,FI)
C*****************************************************************************
C     A ROUTINE TO CARRY OUT NONLINEAR ANALYSIS BY MEANS OF NEWTON
C      RAPHSON OR MODIFIED NEWTON RAPHSON METHOD.
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/TWO/NVR,NO,NE,NEQ,NMX,NMT
      COMMON/THREE/E,ET,SIGY,SIGU
      COMMON/FOUR/XD(100),YD(100),ICOD(2,100)
      DIMENSION JX(1),PE(1),PT(1),NOW(1),DT(1),RR(1),FI(1),RT(1),DR(1)
     @,DEL(21),DEP(21),LJ(6),BS(6),FL(6),BETA(50),SL(52),WZ(7)
     @,SIG(21),DSG(21),EPS(21),DPS(21),PLOAD(3),W(3),X(3),WL(52)
     @,GS(1),WK(6,6),MDIA(1),TE(6,6),FAL(21),FG(6),DM1(1),DM2(1),DM3(1),
     @WD(3),TH(3),BL(126),BNL(126),BT(126),STL(6,6),STG(6,6),STT(6,6),
     @UTL(6),UTG(6),GGT(108),DIS(100)
      REWIND NTP1
      REWIND NTP2
      REWIND NTP3
      REWIND NTP4
      REWIND NTP5
C     WRITE(NTPO,1999)
C     READ(NTPI, * )MTH
      MTH=1
C     IF(MTH.EQ.1)WRITE(NTPO,2000)
C     IF(MTH.EQ.2)WRITE(NTPO,2001)
      NLO=50
      NIT=10
```

```
      FACU=SIGY/SIGU
      TOL=0.001
      SL(1)=0.0
      CALL NORMS(DNORM,JX,NMX,DT,FI)
      CALL NORMS(FNORM,JX,NMX,PT,FI)
      SL(2)=FNORM/DNORM
      WL(1)=0.0
      WL(2)=1.0
      NP1=NTP4
      NP2=NTP3
      NS1=NTP5
      NS2=NTP2
C
      DO 10 I=1,NEQ
      RR(I)=0.0
      FI(I)=0.0
      RT(I)=0.0
   10 DR(I)=0.0
C
      DO 20 I=1,NLO
   20 BETA(I)=1.00
      CALL PRELIM(W,X,DEL,WZ)
C
      DO 1000 ILO=1,NLO
      ILOACT=ILO+1
      WRITE(NTPO,3000)ILOACT,BETA(ILO)
C     TOTAL EXTERNAL LOAD,
19874 DO 30 I=1,NEQ
   30 PT(I)=PT(I)+BETA(ILO)*PE(I)
C     CALCULATE LOAD INCREMENT
      DO 40 I=1,NEQ
   40 DR(I)=RR(I)+PE(I)*BETA(ILO)
      CALL NORMS(FNORM,JX,NMX,DR,FI)
      DO 45 I=1,NEQ
      FI(I)=DR(I)
   45 RT(I)=DT(I)
C
C ***********  REWIND STRESS FILE FOR PLOTTING*****************
C     REWIND NTP8
      DO 900 IT=1,NIT
      LT=2
      IF(MTH.EQ.1)LT=1
      IF(IT.EQ.1)LT=1
      IF(IT.EQ.1.AND.ILO.EQ.1)LT=2
      CALL COLSOL(GS,DR,MDIA,NEQ,NMT,LT)
      DO 101 I=1,NMX
      J=JX(I)
      DIS(I)=0.0
      IF(J.GT.0) DIS(I)=DR(J)
  101 CONTINUE
      DO 202 I=1,NO
      IX=(I-1)*3+1
```

```
      IY=IX+1
      XD(I)=XD(I)+DIS(IX)
      YD(I)=YD(I)+DIS(IY)
  202 CONTINUE
C**********************UPDATE CO-ORDINATES OF THE NODES*****************
      IF(LT.LT.0)GO TO 1010
      IF(IT.GT.1) GOTO 53
      EINC=0.0
      DO 52 I=1,NEQ
   52 EINC=EINC+DR(I)*FI(I)
   53 WKD=0.0
      DO 54 I=1,NEQ
      WKD=WKD+RR(I)*DR(I)
   54 CONTINUE
C     CALCULATE INITIAL INTERNAL ENERGY INCREMENT
C     TOTAL DISPLACEMENTS
  203 DO 50 I=1,NEQ
   50 DT(I)=DT(I)+DR(I)
   55 CONTINUE
      IF(NP1-NP2)60,70,70
   60 NP1=NTP4
      NP2=NTP3
      GO TO 80
   70 NP1=NTP3
      NP2=NTP4
   80 IF(NS1-NS2)112,114,114
  112 NS1=NTP5
      NS2=NTP2
      GO TO 116
  114 NS1=NTP2
      NS2=NTP5
  116 CONTINUE
C
      EPSULT=0.25
      REWIND NTP1
      REWIND NS1
      REWIND NS2
      REWIND NP1
      REWIND NP2
      IF(MTH.EQ.1)CALL PSET(GS,NMT)
      CALL PSET(FI,NEQ)
      DO 200 IE=1,NE
      READ (NTP1)(BL(J),J=1,126),(GGT(J),J=1,108)
      READ (NS1) ((STT(I,J),I=1,6),J=1,6),(LJ(J),J=1,6),AL,WD,TH,
     @((TE(K,L),K=1,6),L=1,6),ITT,IFF
C       CALCULATE TOTAL ELEMENT DISPLACEMENTS
C       EXTRACT GLOBAL DISPLACEMENTS
        DO 551 K=1,6
        KK=LJ(K)
        UTG(K)=0.0
        IF(KK.GT.0) UTG(K)=DT(KK)
551     CONTINUE
```

```
        DO 553 K=1,6
        UTL(K)=0.0
        DO 553 L=1,6
        UTL(K)=UTL(K)+TE(K,L)*UTG(L)
553     CONTINUE
C       CALCULATE BNL,BL AND BT
         CALL BEENL(BNL,UTL,GGT)
         DO 786 KI=1,126
786      BT(KI)=BL(KI)+BNL(KI)
      READ (NP1)(EPS(J),J=1,21),(SIG(J),J=1,21),(DEP(J),J=1,21)
      CALL STRESS(BT,DR,LJ,DPS,DSG,DEP,6,21,TE)
      A1=TH(1)*WD(1)
      A2=TH(2)*WD(2)
      A3=TH(3)*WD(3)
C
C     CHECK YIELDING OF ELEMENTS
      DO 120 I=1,21
      FAL(I)=1.0
      SGP=DABS(SIG(I))
      SGI=DABS(DSG(I))
      SGN=DABS(SIG(I)+DSG(I))
      IF(SGP.GT.SGN)GO TO 117
      IF(SGP.LT.SIGY.AND.SGN.GE.SIGY)GO TO 118
      SIG(I)=SIG(I)+DSG(I)
      GO TO 119
C     117 ELASTIC UNLOADING
 117  SIG(I)=SIG(I)+E*DPS(I)
        DEP(I)=E
      GO TO 119
C     118 ELASTIC-TO-PLASTIC TRANSITION
C118  IF(SGI.LT.1.E-4)SGI=1.E-4
 118  BITA=(SIGY-SGP)/SGI
      SIG(I)=SIG(I)+BITA*DSG(I)+(1.0-BITA)*ET*DPS(I)
      DEP(I)=ET
 119  EPS(I)=EPS(I)+DPS(I)
      IF(DABS(SIG(I)).GE.SIGU)DEP(I)=0.0
  120 CONTINUE
      WRITE(NP2)(EPS(J),J=1,21),(SIG(J),J=1,21),(DEP(J),J=1,21)
C   *******  WRTIE STRESSES FOR PLTTING THE YIELD ZONES***********
C     WRITE(NTP8,2151) (SIG(KK),KK=1,21)
 2151  FORMAT(5E15.6)
C# CALCULATE INITIAL STIFFNESS MATRIXAND TRANSFER TO GLOBALCOORDINATES
C##########   CALCULATE THE TOTAL STIFFNESS MATRIX
      CALL STIFF2(STL,AL,TH,WD,W,X,DEP,TE,WK,ITT,2,BT,BS,WZ)
125      CALL INITK(AL,WD(1),TH(1),TH(2),WD(2),SIG,STG,TE)
         DO 906 MM =1,6
         DO 906 NN=1,6
906      STT(MM,NN)=STL(MM,NN)+STG(MM,NN)
C
C     COMPUTE ELEMENT INTERNAL FORCES IN LOCAL CO-ORDINATES
      CALL PSET(FL,6)
      DO 170 K=1,3
```

```
      DO 170 L=1,7
      KL=7*(K-1)+L
      KLM=6*(KL-1)
      IF(L.LE.2)ABT=AL*W(K)*WZ(L)*A1/12.0
      IF(L.EQ.3)ABT=AL*W(K)*WZ(L)*(A1+A2)/12.0
      IF(L.EQ.4)ABT=AL*W(K)*WZ(L)*A2/12.0
      IF(L.EQ.5)ABT=AL*W(K)*WZ(L)*(A2+A3)/12.0
      IF(L.GT.5)ABT=AL*W(K)*WZ(L)*A3/12.0
      DO 160 J=1,6
      II=KLM+J
  160 FL(J)=FL(J)+ABT*BT(II)*SIG(KL)
  170 CONTINUE
C     TRANSFORM TO GLOBAL CO-ORDINATES
      DO 176 J=1,6
      FG(J)=0.0
      DO 175 I=1,6
  175 FG(J)=FG(J)+TE(I,J)*FL(I)
  176 CONTINUE
      IF(MTH.EQ.1)GO TO 190
C     ADD UP ELEMENT FORCES TO FI(NEQ) FOR MODIFIED N.R.M.
      DO 180 I=1,6
      LJR=LJ(I)
      IF(LJR.EQ.0)GO TO 180
      FI(LJR)=FI(LJR)+FG(I)
  180 CONTINUE
      GO TO 195
  190 CALL SETUP3(GS,FI,MDIA,STT,LJ,6,FG)
  195 CALL NEWTR(IE,AL,TE)
      WRITE(NS2)((STT(I,J),I=1,6),J=1,6),(LJ(J),J=1,6),AL,WD,TH,
     @((TE(K,L),K=1,6),L=1,6),ITT,IFF
  200 CONTINUE
C     RESIDUAL LOAD
      DO 340 I=1,NEQ
      RR(I)=PT(I)-FI(I)
  340 CONTINUE
C
C     CHECK CONVERGENCE
C
C     CALCULATE TOLERENCE TO CHECK CONVERGENCE
      UNIT=1.D0+1.D-10
      EROR=WKD/EINC
C      DO NOT CHECK FOR CONVERGENCE AFTER 1 ITERATION
      IF(IT.EQ.1) GOTO 354
C     WRITE(NTPO,7500)IT,EROR
      IF(EROR.LE.TOL )GO TO 910
      IF(EROR.GT.UNIT)GO TO 950
  354 DO 355 I=1,NEQ
  355 DR(I)=RR(I)
  900 CONTINUE
      WRITE(NTPO,3020)NIT
      GOTO 1010
  910 WRITE(NTPO,3030)IT,EROR
```

```
      WL(ILO+2)=WL(ILO+1)+BETA(ILO)
      write(NTP7,2149) WL(ILO+2),DT(1)
      WRITE(NTPO,3031)WL(ILO+2)
C     (1) PRINT CONCENTRATED LOADS
      IF(NLW.EQ.0)GO TO 921
      WRITE(NTPO,3040)
      DO 920 I=1,NLW
      N=NOW(I)
      M1=NVR*(N-1)+1
      M2=M1+NVR-1
      KK=0
      DO 915 J=M1,M2
      KK=KK+1
      PLOAD(KK)=0.0
      JJ=JX(J)
      IF(JJ.EQ.0)GO TO 915
      PLOAD(KK)=PT(JJ)
  915 CONTINUE
  920 WRITE(NTPO,3060)N,(PLOAD(M),M=1,NVR)
C     (2) PRINT DISPLACEMENTS
  921 WRITE(NTPO,3050)
      DO 930 I=1,NO
      M1=(I-1)*NVR+1
      M2=M1+NVR-1
      KK=0
      DO 925 J=M1,M2
      KK=KK+1
      PLOAD(KK)=0.0
      JJ=JX(J)
      IF(JJ.EQ.0)GO TO 925
      PLOAD(KK)=DT(JJ)
  925 CONTINUE
C     (3) PRINT ELEMENT INTERNAL FORCES
C     CALL FORCES(DT,STT,TE,LJ,U,FL,FG,NS2)
  930 WRITE(NTPO,3060)I,(PLOAD(M),M=1,NVR)
C     (4) PRINT STRESSES OF YIELDED ELEMENTS
      REWIND NP2
      NPLAST=0
      DO 970 IEL=1,NE
      READ(NP2)(EPS(J),J=1,21),(SIG(J),J=1,21),(DEP(J),J=1,21)
      CALL PRNTYE(EPS,SIG,X,IEL,NPLST)
      IF(NPLST.GT.0)NPLAST=NPLAST+1
  970 CONTINUE
      WRITE(NTPO,3051)NPLAST
C
C     SIZE OF NEXT LOAD INCREMENT
      DO 975 I=1,NEQ
  975 RT(I)=DT(I)-RT(I)
      CALL NORMS(DNORM,JX,NMX,RT,FI)
      SL(ILO+2)=FNORM/DNORM
      RAT=SL(ILO+2)/SL(2)
999   CALL LODINC(RAT,BETA,NLO,ILO)
```

```
       IF(LT.LT.0.0) BETA(ILO+1)=-0.05
      IF(MTH.EQ.1)GO TO 1000
C     UPDATE THE GLOBAL STIFFNESS MATRIX
      CALL PSET(GS,NMT)
      CALL PSET(FI,NEQ)
      CALL PSET(FL,6)
      REWIND NS2
      DO 934 IE=1,NE
      READ (NS2)((STT(I,J),I=1,6),J=1,6),(LJ(J),J=1,6),AL,WD,TH,
     @((TE(K,L),K=1,6),L=1,6),ITT,IFF
      CALL SETUP3(GS,FI,MDIA,STT,LJ,6,FL)
  934 CONTINUE
 1000 CONTINUE
      GO TO 1010
  950 WRITE(NTPO,3090)
 1010 WRITE(NTPO,3070)
C************ SUBTRACT DISPLACEMENTS IF STRUCTURE COLLAPSES*************
        if(LT.LT.0.OR.EROR.GT.UNIT) THEN
      DO 208 I=1,NO
      IX=(I-1)*3+1
      IY=IX+1
      XD(I)=XD(I)-DIS(IX)
      YD(I)=YD(I)-DIS(IY)
 208  CONTINUE
        END IF
C      write(NTP6,2150) ILO
      IPL=ILO+2
      DO 940 I=1,IPL
      ILOAD=I-1
  940 WRITE(NTPO,3080)ILOAD,WL(I),SL(I)
      RETURN
C************************** F O R M A T ***********************************
C
 1999 FORMAT(5X,'N O N L I N E A R    A N A L Y S I S',///)
 2000 FORMAT(5X,'      NEWTON RAPHSON METHOD          ',//)
 2001 FORMAT(5X,'   MODIFIED NEWTON RAPHSON METHOD    ',//)
 3000 FORMAT(//,5X,16(1H*),5X,'SOLUTION FOR LOAD INCREMENT NO.',I2,5X,
     $16(1H*),//,5X,'LOAD INCREMENT = ',F6.2)
 3020 FORMAT(5X,'AFTER',I3,' ITERATIONS, SOLUTION DOES NOT CONVERGE',/)
 3030 FORMAT(5X,'***  CONVERGENCE  ***',/,5X,'AFTER ',I2,
     $' ITERATIONS, TOLERENCE =',E12.5,/)
 3031 FORMAT(5X,'LOAD LEVEL   = ',F12.5,' X  REFERENCE LOAD')
 3040 FORMAT(//,5X,'TOTAL LOADS',//,
     $5X,'NODE',8X,'FX',13X,'FY',13X,'M',/)
 3050 FORMAT(//,5X,'NODAL DISPLACEMENTS',//,
     $5X,'NODE',8X,'X-DIR',10X,'Y-DIR',10X,'ROT',/)
 3051 FORMAT(5X,'***  NO. OF YIELDING ELEMENTS = ', I3,/)
 3060 FORMAT(5X,I4,3E15.5)
 3070 FORMAT(1H1,5X,15(1H*),5X,'S U M M A R Y    OF    R E S U L T S'
     $,5X,15(1H*),///,5X,'LOAD',10X,'LOAD',29X,'NOMINAL',/,
     @                5X,'INCR',10X,'LEVEL',26X,'STIFFNESS',//)
 3080 FORMAT(5X,I4,8X,F6.2,'  X  REFERENCE LOAD',6X,E15.5)
```

```
 3090 FORMAT(5X,'SOLUTION IS DIVERGING- FAILURE IS IMMINENT')
 4010 FORMAT(5X,I5,4E12.5)
 7500 FORMAT(5X,'AFTER ',I2,' ITERATIONS, ERROR = ',F10.5,/)
 7600 FORMAT(5X,'POST-COLLAPSE SOLUTION UNTRACABLE')
 2149 format(2e15.6)
 2150 format(i5)
      END
      SUBROUTINE NORMS(UN,JX,NMX,A,WK)
C*****************************************************************************
C     A ROUTINE TO COMPUTE THE NORM OF AN ARRAY A
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION JX(1),A(1),WK(1)
      UN=0.D0
      NN=NMX/3
      DO 10 I=1,NN
      DO 10 J=1,3
      KL=(I-1)*3+J
      WK(KL)=0.0
      IF(JX(KL).EQ.0)GO TO 10
      WK(KL)=A(JX(KL))
      IF(J.EQ.3)GO TO 10
      UN=UN+WK(KL)**2
  10  CONTINUE
      UN=UN**0.50
      RETURN
      END
      SUBROUTINE OUPUTF( string,file2,file4)
      implicit integer*2 (a-z)
      character*35 intfil,string*31,value(31)*1,value2(35)*1,blank,
     +             file2,file4
c
        write(intfil,'(a35)') blank
c
        write(intfil,'(a31)') string
c
        do 11 j=1,31
 11     value(j)=' '
c
        read(intfil,2000) value
 2000   format(31a1)
c
        i=0
        do  4001  j=1,31
        if( value(j).eq.'.') then
          i= 32-j
          goto 5
        end if
 4001   continue
c
c---------------------  check the length of the filename
```

```
c
      i=0
      do 4000 j=1,31
      if( value(j).eq.' ') i=i+1
 4000 continue
c
 5       k = 31 - i
         l = k + 1
         m = k + 2
         n = k + 3
         o = k + 4
c------------------------------------  assign the file extensions
c        write(2,*) i
c        write(2,*) k
         if( k.le.31) then
c
           do 10 j=1,35
 10        value2(j)=' '
c
           do 20 j=1,k
 20        value2(j)=value(j)
c
           value2(l)='.'
c
c          value2(m)='c'
c          value2(n)='d'
c          value2(o)='s'
c         write(intfil,'(35a1)') value2
c         read(intfil,'(a35)') file1
c
           value2(m)='p'
           value2(n)='d'
           value2(o)='1'
          write(intfil,'(35a1)') value2
          read(intfil,'(a35)') file2
c
c          value2(m)='s'
c          value2(n)='t'
c          value2(o)='s'
c         write(intfil,'(35a1)') value2
c         read(intfil,'(a35)') file3
c
           value2(m)='d'
           value2(n)='o'
           value2(o)='c'
          write(intfil,'(35a1)') value2
          read(intfil,'(a35)') file4
         else
c        file1='steel2d.cds'
         file2='steel2d.pdl'
c        file3='steel2d.sts'
         file4='steel2d.doc'
```

```
      end if
      return
      end
      SUBROUTINE PRELIM(W,X,D,WZ)
C*************************************************************************
C     A ROUTINE TO COMPUTE POINT CO-ORDINATES AND WEIGHT FACTORS
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/THREE/E,ET,SIGY,SIGU
      DIMENSION W(3),X(3),D(1),WZ(1)
      W(1)=5.0/9.0
      W(2)=8.0/9.0
      W(3)=5.0/9.0
      X(1)=0.50-0.15**0.50
      X(2)=0.50
      X(3)=0.50+0.15**0.50
      DO 1 I=1,21
  1   D(I)=E
      WZ(1)=1.0
      WZ(2)=4.0
      WZ(3)=1.0
      WZ(4)=4.0
      WZ(5)=1.0
      WZ(6)=4.0
      WZ(7)=1.0
      RETURN
      END
      SUBROUTINE PRESET(A,M,N)
C*************************************************************************
C     A ROUTINE TO ZERO A TWO DIMENSIONAL ARRAY
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION A(M,N)
      DO 1 I=1,M
      DO 2 J=1,N
    2 A(I,J)=0.D0
    1 CONTINUE
      RETURN
      END
      SUBROUTINE PSET(A,M)
C*************************************************************************
C     A ROUTINE TO ZERO A ONE DIMENSIONAL ARRAY
C*************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION A(1)
      DO 1 I=1,M
    1 A(I)=0.D0
      RETURN
      END
```

```
      SUBROUTINE PRNTYE(EPS,SIG,XI,IE,NPL)
C*****************************************************************************
C     A ROUTINE TO PRINT STRESSES AND STRAINS OF YIELDED ELEMENTS
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      COMMON/ONE/NTPI,NTPO,NTP1,NTP2,NTP3,NTP4,NTP5,NTP6,NTP7,NTP8
      COMMON/THREE/E,ET,SIGY,SIGU
      DIMENSION EPS(1),SIG(1),XI(1),Z(7)
      NPL=0
      F1=0.999
      DO 10 I=1,21
      F2=DABS(SIG(I))/SIGY
      IF(F2.LT.F1)GO TO 10
      NPL=NPL+1
   10 CONTINUE
      IF(NPL.EQ.0)RETURN
      DZ=1.0/6.0
      DO 15 I=1,7
      Z(I)=-2.0/3.0+DZ*I
   15 CONTINUE
      WRITE(NTPO,30)IE
      DO 20 I=1,3
      DO 20 J=1,7
      IP=(I-1)*7+J
   20 WRITE(NTPO,40)IP,XI(I),Z(J),SIG(IP),EPS(IP)
   30 FORMAT(5X,'*****  YIELDING OF ELEMENT NO. ',I5,'  *****',//,
     @5X,'POINT   X-CRD   Y-CRD    STRESS          STRAIN',/)
   40 FORMAT(5X,I5,2F8.4,2(E12.5,5X))
      RETURN
      END
      SUBROUTINE SETUP3(A,B,MDIA,S,LJ,NVEL,FL)
C*****************************************************************************
C     A ROUTINE TO ASSEMBLE A SKYLINED MATRIX                                 *
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION A(1),B(1),MDIA(1),S(NVEL,1),LJ(1),FL(1)
      DO 200 I=1,NVEL
      LJR=LJ(I)
      IF(LJR) 200,200,100
  100 B(LJR)=B(LJR) + FL(I)
      DO 220 J=I,NVEL
      LJC=LJ(J)
      IF(LJC) 220,220,110
  110 IJ=LJR-LJC
      IF(IJ) 210,215,215
  210 MJ=MDIA(LJC)
      IJ=-IJ
      GO TO 216
  215 MJ=MDIA(LJR)
  216 KK=MJ+IJ
```

```
      A(KK)=A(KK)+S(I,J)
  220 CONTINUE
  200 CONTINUE
      RETURN
      END
      SUBROUTINE STIFF2(ST,AL,TH,WD,W,X,ET,T,WK,IT,IS,BB,BS,WZ)
C*****************************************************************************
C  A ROUTINE TO COMPUTE THE STIFFNESS MATRIX OF BEAM COLUMN ELEMENTS
C  WITH OPEN OR RECTANGULAR HOLLOW SECTIONS.
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION ST(6,1),W(1),X(1),ET(1),T(6,1),WK(6,1),BB(1),BS(1),Z(7),
     $WZ(1),ST1(6,6),TH(1),WD(1)
      IF(IS.EQ.0)RETURN
      CALL PRESET(ST,6,6)
      CALL PRESET(ST1,6,6)
      A1=TH(1)*WD(1)
      A2=TH(2)*WD(2)
      A3=TH(3)*WD(3)
        IF(IS.EQ.2) GOTO 100
      AT=0.0
      ATY=0.0
      DO 10 I=1,3
      AT=AT+WD(I)*TH(I)
  10  ATY=ATY+WD(I)*TH(I)**2/2.0
      ATY=ATY+WD(2)*TH(2)*TH(1)+WD(3)*TH(3)*(TH(1)+TH(2))
      YB =ATY/AT
      Z(1)=-YB
      Z(2)=Z(1)+TH(1)/2.0
      Z(3)=Z(2)+TH(1)/2.0
      Z(4)=Z(3)+TH(2)/2.0
      Z(5)=Z(4)+TH(2)/2.0
      Z(6)=Z(5)+TH(3)/2.0
      Z(7)=Z(6)+TH(3)/2.0
      IF(IT.GT.1)GO TO 50
      CALL PSET(BS,6)
      BS(1)=-1.0/AL
      BS(4)= 1.0/AL
      DO 40 I=1,21
      KL=6*(I-1)
      DO 30 II=1,6
  30  BB(II+KL)=BS(II)
  40  CONTINUE
      GO TO 100
  50  KK=0
      DO 70 K=1,3
      DO 70 L=1,7
      KL=6*KK
      XT=X(K)
      ZT=Z(L)
      BS(1)=-1.0/AL
```

```
      BS(2)=6.*ZT*(1.-2.*XT)/AL**2
      BS(3)=2.*ZT*(2.-3.*XT)/AL
      BS(4)=-BS(1)
      BS(5)=-BS(2)
      BS(6)=2.*ZT*(1.-3.*XT)/AL
      IF(IT.EQ.2)GO TO 55
      BS(2)=3.0*ZT*XT/AL**2
      BS(5)=-BS(2)
      BS(3)=0.0
      BS(6)=3.0*ZT*XT/AL
      IF(IT.EQ.3)GO TO 55
      BS(3)=BS(6)
      BS(6)=0.0
   55 DO 60 II=1,6
   60 BB(II+KL)=BS(II)
   70 KK=KK+1
  100 KK=0
      DO 4 K=1,3
      DO 4 L=1,7
      KL=7*(K-1)+L
      IF(L.LE.2)ABT=AL*ET(KL)*W(K)*WZ(L)*A1/12.0
      IF(L.EQ.3)ABT=AL*ET(KL)*W(K)*WZ(L)*(A1+A2)/12.0
      IF(L.EQ.4)ABT=AL*ET(KL)*W(K)*WZ(L)*A2/12.0
      IF(L.EQ.5)ABT=AL*ET(KL)*W(K)*WZ(L)*(A2+A3)/12.0
      IF(L.GT.5)ABT=AL*ET(KL)*W(K)*WZ(L)*A3/12.0
      KLM=6*KK
      DO 3 I=1,6
      DO 3 J=1,I
      II=KLM+I
      JJ=KLM+J
    3 ST1(I,J)=ST1(I,J)+ABT*BB(II)*BB(JJ)
    4 KK=KK+1
      DO 5 I=1,6
      DO 5 J=1,I
    5 ST1(J,I)=ST1(I,J)
      ONE=1.0
      CALL TRANS(ST1,T,ST,WK,6,6,ONE)
      RETURN
      END
      SUBROUTINE TRANS(S,T,R,W,M1,M2,CONST)
C*****************************************************************************
C     THIS ROUTINE MULTIPLIES 3 MATRICES IN THE FORM:                          *
C     (R) = CONSTANT * (T)TRANSPOSE * (S) * (T)                                *
C*****************************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
      DIMENSION S(M1,M1),T(M1,M2),W(M2,M1),R(M2,M2)
      CALL PRESET(R,M2,M2)
      CALL PRESET(W,M2,M1)
      DO 10 I=1,M2
      DO 10 J=1,M1
      DO 10 K=1,M1
```

```
   10  W(I,J)=W(I,J)+CONST*T(K,I)*S(K,J)
       DO 20 I=1,M2
       DO 20 J=1,M2
       DO 20 K=1,M1
   20  R(I,J)=R(I,J)+W(I,K)*T(K,J)
       RETURN
       END
       SUBROUTINE STRESS(BT,DIS,LJ,DPS,DSG,DEP,NVEL,NSP,TE)
C*************************************************************************
C      A ROUTINE TO CALCULATE THE ELEMENT STRESS AND STRAIN INCREMENTS
C*************************************************************************
       IMPLICIT REAL*8(A-H,O-Z)
       INTEGER*2 NE,NO,NSTP,NLTP,NE1,NE6
       DIMENSION BT(1),DIS(1),LJ(1),DPS(1),DSG(1),DEP(1),TE(6,1),U(6)
      @,UL(6)
C      EXTRACT GLOBAL DISPLACEMENT
       DO 10 I=1,NVEL
       KK=LJ(I)
       U(I)=0.0
       IF(KK.GT.0)U(I)=DIS(KK)
   10  CONTINUE
C
C      TRANSFORM TO GLOBAL CO-ORDINATES
       DO 30 I=1,NVEL
       UL(I)=0.0
       DO 20 J=1,NVEL
       UL(I)=UL(I)+TE(I,J)*U(J)
   20  CONTINUE
   30  CONTINUE
C
C      STRAIN INCREMENT
       DO 50 I=1,NSP
       DPS(I)=0.0
       DO 40 J=1,NVEL
       NN=(I-1)*6+J
   40  DPS(I)=DPS(I)+BT(NN)*UL(J)
   50  CONTINUE
C
C      STRESS INCREMENT
       DO 60 I=1,NSP
       DSG(I)=DEP(I)*DPS(I)
   60  CONTINUE
   100 FORMAT(5X,'STRESS INCR =',/,3(7F10.4,/))
       RETURN
       END
```